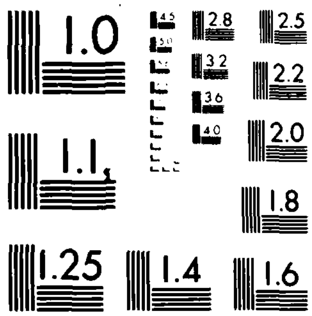
AD-A129 581 USAF (UNITED STATES AIR FORCE) ACADEMY WIND SITE SURVEY: METHODOLOGIES FO..(U) AIR FORCE ENGINEERING AND SERVICES CENTER TYDALL AFB FL ENGIN.. 1/2

UNCLASSIFIED T E KULLGREN ET AL. MAR 83 F/G 4/2 NL


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

ESL-TR-81-02

AD A 129 58

# USAF ACADEMY WIND SITE SURVEY; METHODOLOGIES FOR USE BY THE AIR FORCE


THOMAS E. KULLGREN, THOMAS C. FINLEY, STEVEN C. BOYCE

DEPARTMENT OF ENGINEERING MECHANICS AND
DEPARTMENT OF CIVIL ENGINEERING
UNITED STATES AIR FORCE ACADEMY, CO 80840


MARCH 1983

FINAL REPORT
MAY 1977 - DECEMBER 1980



ENGINEERING AND SERVICES LABORATORY
AIR FORCE ENGINEERING AND SERVICES CENTER
TYNDALL AiR FORCE BASE, FLORIDA 32403

# DISCLAIMER NOTICE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

| | | |
|---|---|---|
| 1. REPORT NUMBER<br>ESL-TR-81-02 | 2. GOVT ACCESSION NO.<br>AD-A129 581 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>USAF Academy Wind Site Survey; Methodologies for Use by the Air Force | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final Report<br>May 1977-December 1980 |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>Thomas E. Kullgren<br>Thomas C. Finley<br>Steven C. Boyce | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Department of Engineering Mechanics and<br>Department of Civil Engineering<br>United States Air Force Academy, CO 80840 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>PE 63723F<br>JON 21038011 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Air Force Engineering and Services Center (RDVA)<br>Tyndall AFB, FL 32403 | | 12. REPORT DATE<br>March 1983 |
| | | 13. NUMBER OF PAGES<br>161 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION DOWNGRADING SCHEDULE N/A |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release, Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Availability of this report is specified on reverse of Front Cover.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Wind Energy
Wind Resource Assessment
Wind Site Surveying
Air Force Wind Program

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a wind site survey to locate potential high energy sites at the USAF Academy for future wind machine installation. Surveying techniques developed during the project are described and illustrated. Site-specific results, including wind characteristics and economic analyses, are presented. Three wind site surveying methodologies are presented.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

This report was prepared by members of the Departments of Engineering Mechanics (DFEM) and Civil Engineering (DFCE), United States Air Force Academy (USAFA), Colorado. This work was initiated for the Air Force Civil and Environmental Engineering Development Office (CEEDO) by Lt Michael Mantz, under Project Order No. 77-037 in May 1977; it continued under Project Orders DTC-8-123, DTC-9-30, and SO-80-8 through fiscal years 1978, 1979, and 1980, respectively. The final Air Force Engineering and Services Center (AFESC/RDVA) Project Officer was Major Gary G. Worley.

Captain Arthur R. Fisher was the principal USAFA investigator for the first 6 months and Lt Colonel Thomas E. Kullgren for the remainder of this project. In addition to the authors, the following associate investigators, research assistants and students worked on the project and drafted portions of this report:

| | |
|---|---|
| Capt George A. Kehias | - Wind site survey techniques and computer program development |
| Capt Felix T. Uhlik | - Institutional issues and economic analyses |
| 2nd Lt Scott C. Adams | - TALA anemometry procedures and computer program development |
| 2nd Lt Deacon Winters | - Wind site survey techniques and computer program development |
| 2nd Lt Steven T. Lofgren | - Physical site survey and siting extremes |

The authors wish to asknowledge the active support of the Civil Engineering and Engineering Mechanics Laboratory personnel.

This report has been reviewed by the Public Affairs Office (PA), and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

Gary G. Worley

GARY G. WORLEY, Maj, USAF
Research Meteorologist

Michael J. Ryan

MICHAEL J. RYAN, Lt Col, USAF, BSC
Chief, Environics Division

Francis B. Crowley III

FRANCIS B. CROWLEY III, Col, USAF
Director, Engineering and Services Laboratory



(The reverse of this page is blank)

A

## TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONCLUDED)

## LIST OF FIGURES

## LIST OF TABLES

LIST OF TABLES (CONCLUDED)

# SECTION I

# INTRODUCTION

## 1. SCOPE OF THE REPORT

This technical report describes a wind site survey conducted at the United States Air Force Academy from May 1977 to September 1980. Funding for this project was provided by the Air Force Civil and Environmental Engineering Development Organization (CEEDO), Air Force Systems Command, which has been reorganized as a branch of the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida.

The wind site survey is one of two tasks under the USAF Academy (USAFA) Wind Energy Conversion System Project. The other task is the design, fabrication and testing of a small vertical axis wind turbine. This task will not be described here but is fully reported (1). The present report deals not only with results of the wind site survey of the USAF Academy, but also presents methodologies for performing similar surveys at other USAF installations.

## 2. PROJECT MOTIVATION

The USAF Academy Wind Energy Conversion System Project began in 1977 with the sole task of studying a vertical-axis-type wind turbine. Later that year it became apparent that some knowledge of wind characteristics at the selected machine test site was necessary and wind recording instrumentation was installed. In mid-1978 a large effort in wind resource assessment throughout the wind energy community prompted addition of the second project task, that of a wind site survey of the 18,000-acre USAFA installation. As this survey progressed, it became even more apparent that procedures developed at USAFA could be applied to similar surveys of other Air Force bases. Therefore, the wind site survey task was specifically extended at the beginning of FY 1980 to include the development of methodologies to support a uniform USAF-wide approach to wind energy applications. The foresight of these actions is evidenced by specific wind site surveying directives included in the Wind Energy Systems Act of 1980 and discussed in the next section.

3. WIND ENERGY SYSTEMS ACT OF 1980

With the passage of Public Law 96-345 (cited as the "Wind Energy Systems Act of 1980") on 8 September 1980, procedures guaranteeing rapid and efficient applications of wind energy on Air Force installations became a necessity (2). No longer was an individual base approach such as that accomplished at the Air Force Academy sufficient. The Academy survey results are surely part of the required data base, yet all bases must now be considered as a group, with some selection criteria applied.

Table 1 lists extracts from the text of the Wind Energy Systems Act of 1980, along with comments related directly to the present report. It is particularly appropriate to note the directive nature of Section 11(1)(A) and Section 11(1)(B)(1). These sections very specifically detail DOD responsibilities with regrad to economical application of wind systems. The remainder of this report is dedicated to the fulfillment of this particular section.

TABLE 1: EXTRACTS FROM PUBLIC LAW 96-345 (2)

| Section | Text | Comments |
|---|---|---|
| Sec. 3.(5) | The term "known wind resource" means a site with an estimated average annual wind velocity of at least 12 miles per hour. | Fortunately, this definition is applied to only one other place in the law where the DOE Secretary is required to verify locations with "known wind resource." A restriction to only such locations would have eliminated sites with lower potential but having favorable economic factors. |
| Sec. 4.(a) | The program activities shall be conducted in accordance with such a comprehensive plan which shall include:<br>(1) A 5-year program for small wind systems;<br>(2) An 8-year program for large wind energy systems; and<br>(3) A 3-year program for wind resource assessment. | The relatively compact nature of program scheduling requires immediate Air Force actions to comply with this law and to make economic use of wind power. |
| Sec. 6.(c) | In achieving the objectives of this section, the Secretary is authorized to use various forms of federal assistance including, but not limited to -<br>(1) Contracts and cooperative agreements;<br>(2) Grants;<br>(3) Loans; and<br>(4) Direct federal procurement. | It is hoped that Air Force locations will be recipients of directly procured machines. Being competitive in this area will hinge upon hard facts that show economic feasibility. |

TABLE 1: ESTRACTS FROM PUBLIC LAW 96-345 (2) (CONCLUDED)

| Section | Text | Comments |
|---|---|---|
| Sec. 6.(g).(1) | In carrying out his duties under this Act, the Secretary is authorized to provide funds for the accelerated procurement and installation of small and large wind energy systems by Federal agencies. | The key words here are "accelerated" and "Federal agencies"; again underscoring the need for meeting a short suspense in showing Air Force capabilities and potential. |
| Sec. 11 | The Secretary shall -<br>(1) Initiate and conduct a federal application study for wind energy systems, cooperatively, with appropriate Federal agencies, to determine the potential for the use of wind systems at specific Federal facilities; and this study shall -<br>(A) Include an analysis which determines those sites at which wind energy systems are economically competitive with the marginal costs of new conventional energy sources in the areas.<br>(B) Identify potential sites and uses of wind energy systems at DOD and any other agencies the Secretary deems necessary.<br>(1) The Department of Defense; | The text is clear in describing responsibilities of DOD and thus the Air Force. Those locations with the most complete and thorough analysis of potential will surely have the best chance for federal funding. |

## SECTION II

## THE USAF ACADEMY WIND SITE SURVEY EXPERIENCE

### 1. SURVEYING APPROACH

As mentioned in Section I, the USAFA Wind Energy Conversion System Project was first envisioned to involve only the testing and a sample application of a vertical axis wind turbine. In the process of locating a test site for this machine, it became immediately apparent that little was known about wind characteristics at the Air Force Academy. Not only was such information important for wind machine design, but also for determining if the Academy's 18,000-acre installation was a viable site for future wind machine applications. Such a large base with complicated terrain features becomes a real siting challenge, particularly when funding levels do not permit extensive measuring equipment installation. Therefore, a general siting philosophy was employed which called for heavy emphasis on physical prospecting to locate a few potential high energy sites at which fixed instrumentation could be placed for long-term wind measurements.

### 2. EXISTING WEATHER DATA, 1978

Collection of weather information available in 1978 and relevant to the wind site survey of USAFA falls in two categories. First, a literature search was undertaken by Lofgren (3) to determine weather extremes which might affect the safe and efficient operation of a wind machine. General results in the form of comments on these siting extremes are contained in Appendix C. No weather extremes were identified which would preclude the operation of a well-designed wind machine at the Air Force Academy. The second data gathering thrust was directed to the collection of specific wind characteristics. The most extensive local data base is that collected at the City of Colorado Springs Municipal Airport. However, this data was recorded about 20 miles from USAFA and in relatively flat terrain. Therefore, no attempt was made to extend or use this information for the reasons mentioned. A second data set was located which represented wind recording during daylight hours August 1969 to July 1970 at the Air Force Academy Airfield site. While this data is not as extensive as that from the City

of Colorado Springs Airport, the proximity to the more complex USAFA terrain made it more useful. The authors were unable to locate the source document from which the USAFA Airfield data was taken yet, nevertheless, believe it to represent actual results from a survey made to orient the primary runway. Figure 1 shows a wind rose based upon the raw percent occurrence versus wind direction data from the airfield.

## 3. PHYSICAL SURVEY OF USAFA

The wind rose of Figure 1 shows a most definite prevailing wind direction of about 348-153 degrees magnetic. Based upon this finding and assuming the prevailing direction would be maintained in the general wind field over USAFA, prospecting was initiated to locate sites where wind speeds higher than at the airfield might be realized. Concurrently, Meroney, et al., (4) reported wind tunnel results of flow over long ridges oriented perpendicular to the flow direction.. Conclusions centered around dramatic speed increases found close to ridge crests equalling speeds found at much higher elevations over flat terrain. Meroney also concluded that optimum ridge slopes were between 1:2 to 1:4, ridge crests should be smooth and rounded,and vegetation could produce undesirable turbulence. Also, general guidelines indicate ridges should be about 10 times as long as they are high to preclude wind flow around the ends of the ridge rather than over the crest.

Initial visual inspections of the USAFA terrain indicated a number of long ridge lines oriented approximately perpendicular to the prevailing wind directions of Figure 1. An example of such a ridge line is shown in Figure 2. To investigate these ridge lines further, two steps were taken. First, terrain profiles in the prevailing wind direction were produced using a topographical map and the digitizing capability of a desktop computer. These profiles were then used to produce a three-dimensional terrain model and to measure ridge lines for the favorable characteristics mentioned earlier. A physical inspection followed, which included qualitative factors and quantitative measurements of slopes and ridge line lengths. Three primary sites were then selected for fixed instrumentation installation. Characteristics of these sites are listed in Table 2 and locations of primary and secondary sites are shown in Figure 3.

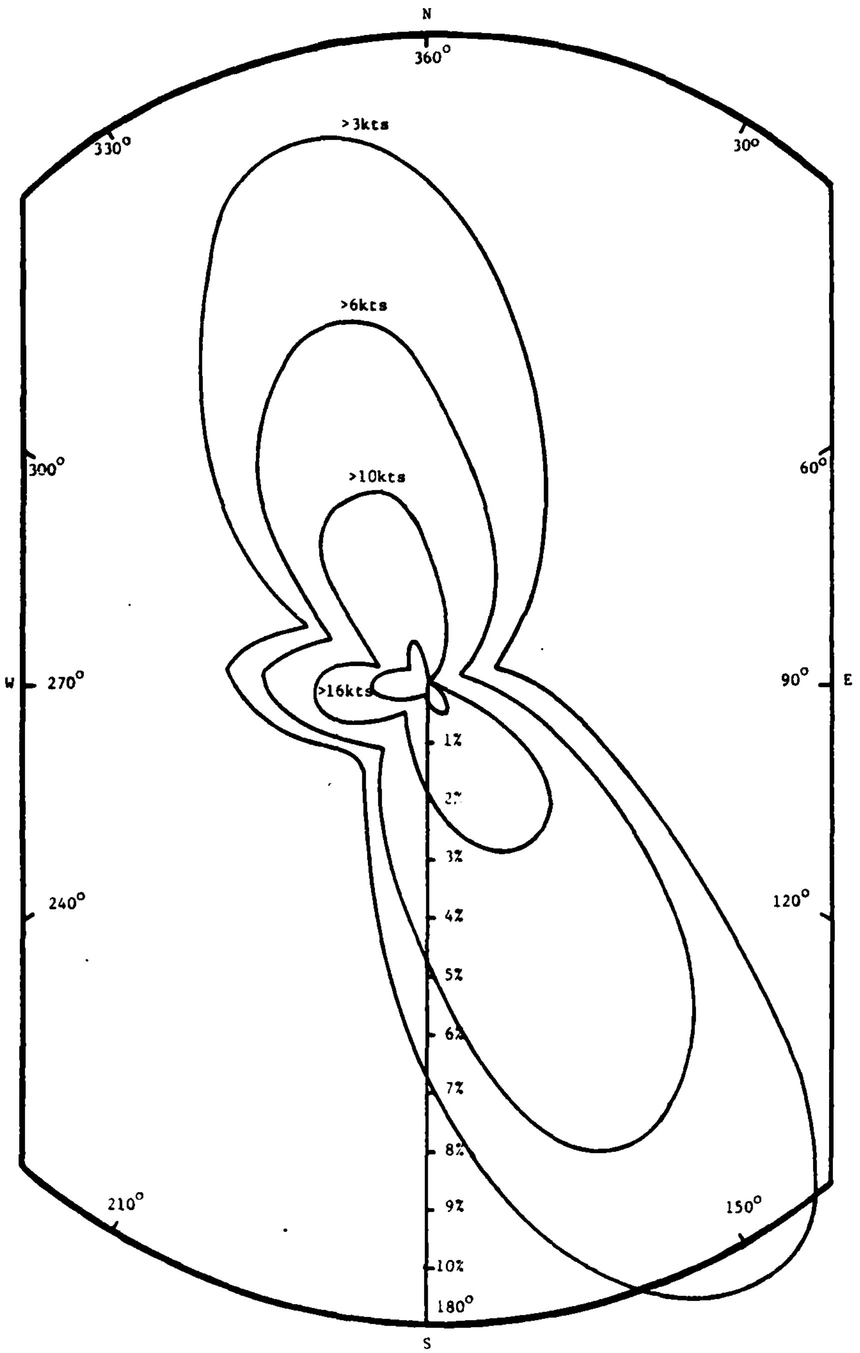



Figure 1. Wind Rose, USAF Academy Airfield, August 1969-July 1970, Daylight Hours

Figure 2. Typical Extensive East-West Ridge Lines,
USAF Academy

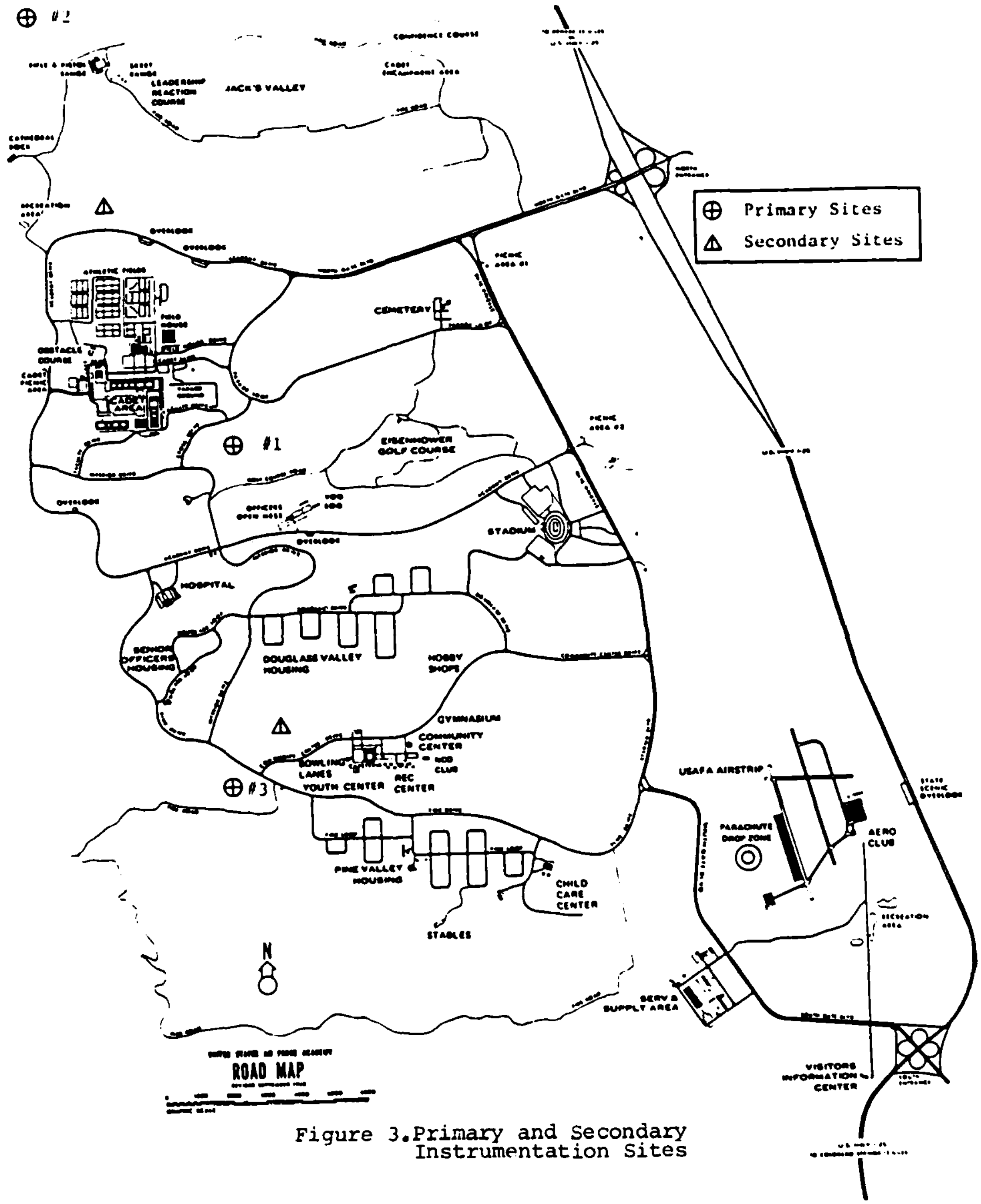



Figure 3. Primary and Secondary Instrumentation Sites

TABLE 2: PRIMARY INSTRUMENTATION SITE CHARACTERISTICS

| Site Number | Slope | | Ridge Line Width at the Crest | Surface Characteristics |
|---|---|---|---|---|
| | North | South | | |
| 1 | 1:2.25 | 1:1.9 | 20 meters | Scrub oak on slopes, treed at crest |
| 2 | 1:2 | 1:2.25 | 20 meters | Scrub oak on slopes, grass at crest |
| 3 | 1:1.25 | 1:1 | 50 meters | Treed on slopes, scrub oak at crest |

## 4. SELECTION AND PLACEMENT OF INSTRUMENTATION

The first site instrumented was the wind turbine test site located just east of Fairchild Hall at the Air Force Academy. A Weather Measure Corporation Remote Recording Skyvane I Wind System, Model W101-DC-DG0-540, was installed late in 1977 to support the design, fabrication and testing of the USAFA Vertical Axis Wind Turbine. The anemometer head was placed on a 4.3-meter (14-foot) tower 9.1 meters (30 feet) north of the wind turbine. Wind speed and direction were continuously recorded on a paper strip chart. The strip charts were analyzed using the digitizing capability of an HP 9830 desktop computer. Strip chart data is generally cumbersome and time consuming to reduce,yet,one cannot fault this method of recording for having too little information. It is an excellent procedure for learning characteristics of the wind, yet, is certainly inappropriate for a mature site survey program.

Instrumentation was also installed in 1978 at the three primary instrumentation sites described in Section II,3. Each anemometer was placed at the top of a 10-meter tower. The towers were installed using portable foundations and guying systems designed and installed by project personnel. Recording devices were battery-powered and housed in weatherproof, locked containers attached to the bottom of the towers. Figures 4 and 5 show the tower and instrumentation at Site #2.

Table 3 describes the installed instrumentation and output form at the three primary sites. Site #1 was chosen as the site for more complete instrumentation. Sites #2 and #3 have simpler devices which allow comparison to the Site #1 output.

TABLE 3: PRIMARY SITE INSTRUMENTATION

| Site Number | Instrumentation Type | Output |
|---|---|---|
| 1 | Wind Speed Compilator, Model A30-131, Natural Power, Inc. | Wind velocity in 32 speed bins and 8 direction bins. Yields wind frequency distribution vs. direction over a recording period. |
| 2,3 | Wind Data Accumulator, Model A20-001, Natural Power, Inc. | Wind run. Yields average wind speed over a recording period. |

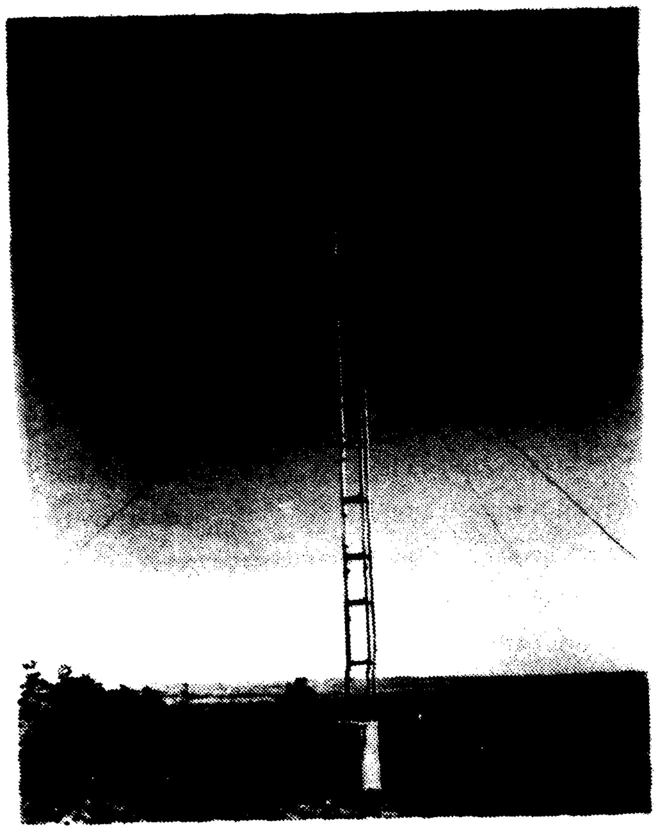


Figure 4.  Site #1, 10-Meter Tower

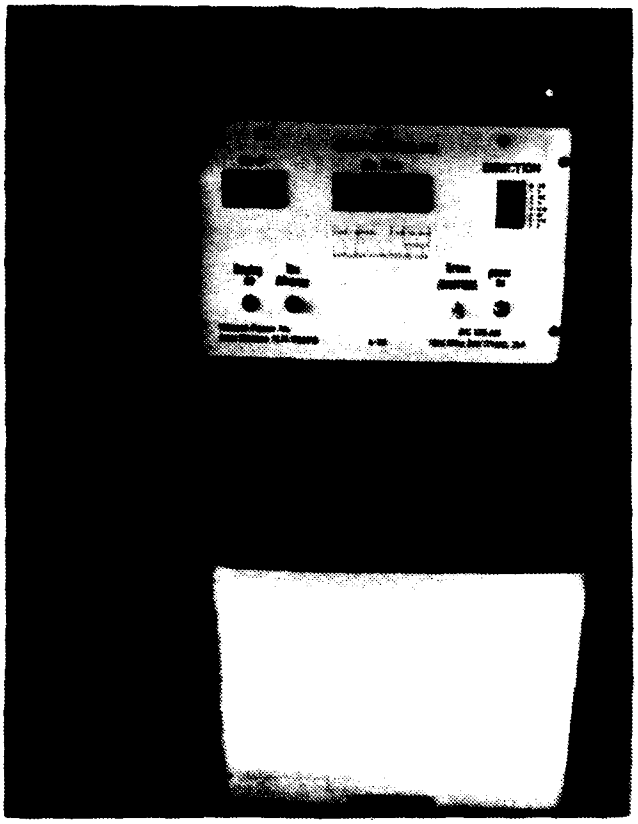


Figure 5. Site #1, Instrumentation

## 5. TALA APPLICATIONS

### a. TALA Anemometer - Basic Description

As described in an earlier section of this report, the fixed instrumentation installed to support the USAFA wind site survey task includes three recording devices on separate 10-meter towers. Each tower is located on crests of long east-west ridge lines in an attempt to assess speed increases expected to occur from prevailing north-south winds. It was recognized early that these towers were probably too low to capture speedup effects, yet, funding restrictions and environmental factors precluded higher towers. Project investigators hoped to either extend tunnel modeling results (4) and/or locate a simple field measuring device to extend the 10-meter findings to realistic large wind machine hub-heights of about 30 meters and coincident with heights where ridge line wind speedup might be seen. Extension of the wind tunnel results was found not feasible due to lack of data for wind directions not perpendicular to the ridge line crest.

Late in 1978 a new product was marketed called the Tethered Aerodynamically Lifting Anemometer or TALA system. This hand-held device is simply a kite connected to a calibrated spring. Tension on the kite string is read, through appropriate calibrations, as wind speed. The angle of the string referenced to horizontal, coupled with string length, leads to flight elevation and the magnetic direction between the operator and kite gives wind direction. The TALA system, disassembled, and, in its carrying case, is shown in Figure 6 and as flown in Figure 7.

Advantages of the TALA system fall in four general categories (5):

(1) Economy. A base purchase price of about $1000 is a fraction of the cost of fixed instrumentation.

(2) Ease of Operation. Setup for a typical flight takes about 5 minutes. One record with 6 readings to altitude takes about 30 minutes.

(3) Simplicity. The entire unit, including the carrying case, weighs only 12 pounds and is small enough for airline carryon. Data recording and flying procedures require minimal training.

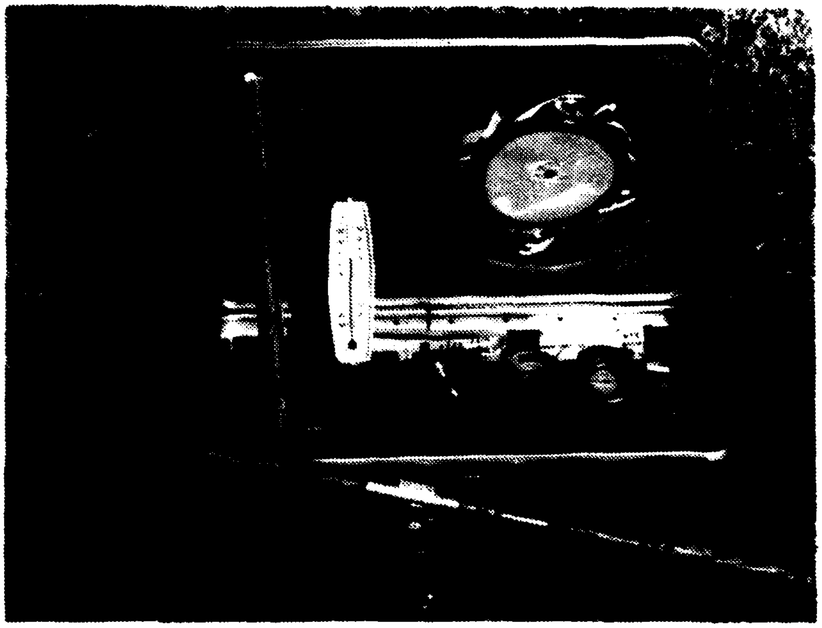


Figure 6. TALA and Accessories

Figure 7. TALA in Flight

(4) Accuracy. Wind tunnel calibrations at NASA Langley show accuracies within 2 percent (6). Some minor criticisms have been leveled at the device, but accuracy is considered to be quite good.

Limitations of the TALA system fall under the general category of operational restrictions and lead to recommendations on use of this device discussed later in this section (5).

(1) Flight Altitude. 300 meters is the upper limit of flight. This is generally well above heights required for wind turbine applications.

(2) Reeling In. Above wind speeds of about 15 m/s, it is physically very difficult and time consuming to reel in the kite from altitude.

(3) Daylight Flight. In the as-supplied condition, TALA is equipped for daylight operation only, since the kite must be seen visually to measure the angle of flight and wind direction. However, a self-contained lightweight beacon could be attached to the kite for nighttime flights.

(4) Time/Wind Field Variations. The wind field at a particular site varies widely with time. If TALA is used for vertical profiling, for example, time "marches on" as the kite is flown at increasing and decreasing altitudes above the site. This procedure takes a finite amount of time during which the general wind characteristics may fluctuate widely, leading to lack of correlation in readings taken at each flight altitude.

b. USAFA Experiences with TALA

The TALA system was purchased early in 1979 for the sole purpose of vertical wind profiling over the three fixed instrumentation sites. Since delivery, this device has been flown over all three locations. Results of these flights are shown in Appendix A.3. The figures shown were generated using a desktop computer and software for vertical profiles. The TALA data recording procedure is detailed in Section IV. 2. A

definite speed increase at about 30 meters above the ridge line is seen in many of the tests and is of enough importance to suggest a higher tower with associated wind recorders should be placed at one of the sites.

As with attempts to extend wind tunnel results to elevations above 10 meters, TALA results could also not be so extended. This is due to the limited number of TALA flights not encompassing a full range of wind velocities, directions and flight altitudes. Even with a full data set, time-of-day, seasonal and yearly wind variations would probably be cause for suspicions that correlations to the 10-meter fixed instrumentation results were inaccurate.

In light of the USAFA experience with the TALA system, some recommendations for its use in the future can be made. First and foremost, TALA can be considered to be a very good prospecting tool. It should not, however, be a replacement for fixed instrumentation but can be used very effectively to locate sites where such instrumentation should be placed. Secondly, TALA can be employed around obstructions to qualitatively locate turbulent areas. The operator's manual (6) describes such a procedure where a vertical line with long tapes attached at regular intervals is flown from the kite. Stable, horizontal tape motion indicates steady winds, while heavy tape flapping indicates undesirable turbulence.

6. SURVEYING RESULTS

a. Wind Characteristics

Tables and figures of Appendix A show monthly and annual wind characteristics for primary instrumentation Site #1 and the wind turbine test site. Also shown are a number of records from TALA flights over the three primary instrumentation sites. Information contained in these tables and figures will be useful for more site-specific activities necessary if and when decisions are made to install wind machines at the USAF Academy. Economic calculations shown in the next section are all based upon annual data reduced for Site #1.

Figure 8 shows approximate monthly and annual average wind speeds for the three primary sites. Missing data points represent instrument maintenance periods. Site #1 shows a slightly higher average annual wind

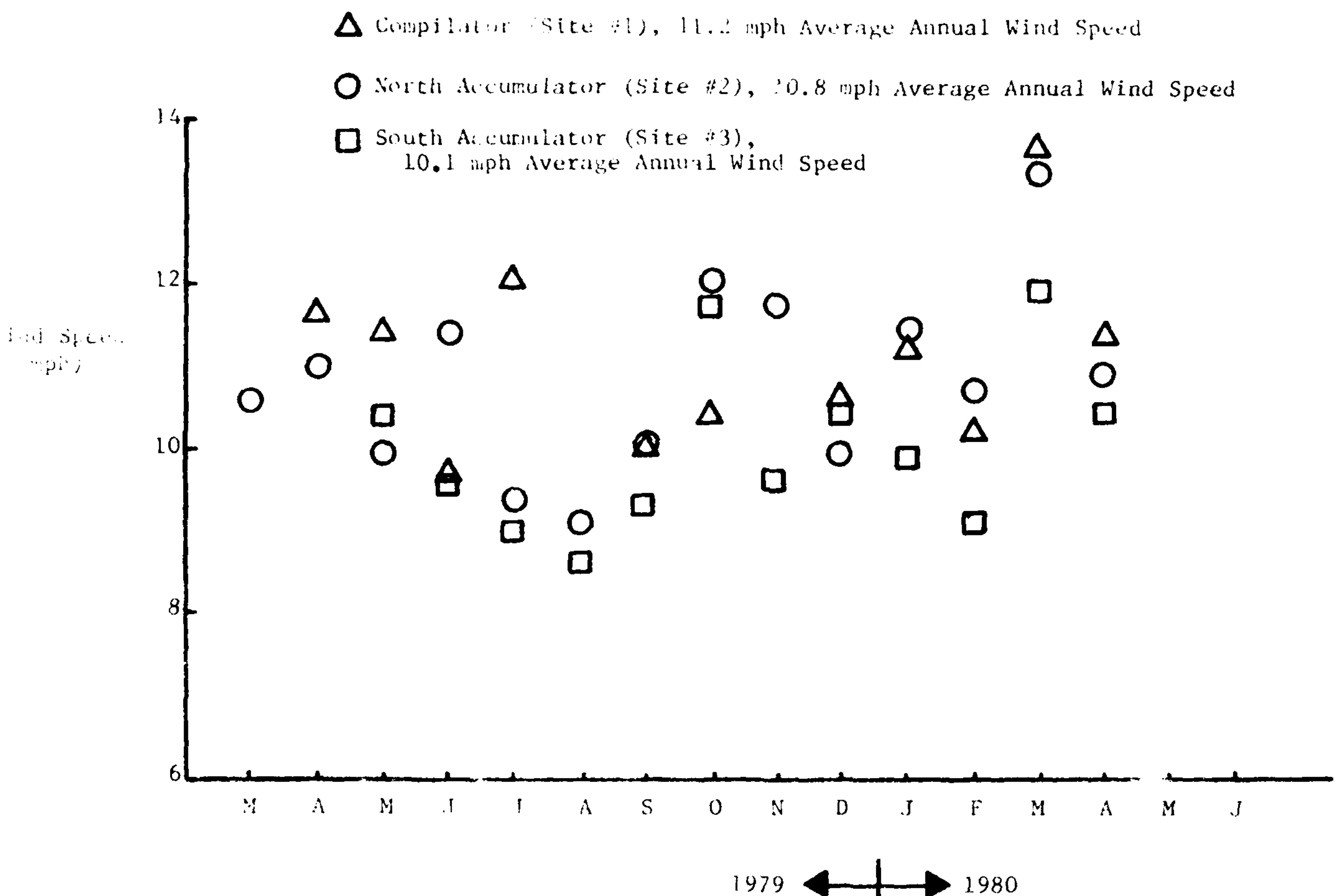



Figure 4. Approximate Monthly Average Wind Speeds at the Three USAFA Instrumentation Sites

speed than the other two sites with Site #3 below the other two. This was not unexpected as Site #3 is less than ideal in terms of ridge line characteristics.

Figure 9 shows a comparison of wind speed duration curves for a number of sites. Grandpa's Knob, the location of the famous Smith-Putnam wind machine, is generally considered to be representative of an excellent site in terms of wind potential. Amarillo Airport represents a good site. All of the Academy sites fall below Amarillo in terms of potential. However, Site #1 exceeds the Academy Airfield in wind speeds above 18 mph. As expected, the wind turbine test site, selected for convenience, is a poor site as evidenced by an approximate average annual wind speed (measured at 14 feet) at 5 mph.

In spite of the implication of Figure 9, the Air Force Academy wind potential may well be greater than measured in this project. Admittedly, 10-meter instrumentation heights were too low to capture the full impact of ridge speedup yet did reveal some benefits above 18 mph. TALA records of Appendix A indicate speedup occurs at heights equal to or greater than 30 meters. This might well boost the category of USAF Academy sites into the 14 mph region required in early DOE candidate site selections.

b. Economic Analysis

Two machines, the Carter Model 25 and the DOE MOD-2, were economically evaluated for possible installation at USAFA. Two techniques described more completely in Section IV ,4., the Approximate (7) and Air Force Method (8), were used. Tables 4 through 6 present the results where all values are to the nearest $100. Line 7 is used to rank order MCP projects. Line entry number 9 on each of the tables gives the year-to-simple-payback with no salvage value assumed and line entry 10 gives the payback factor. Only the MOD-2 appears feasible with the Approximate Method but neither of the machines are self-amortizing,using the Air Force Method.

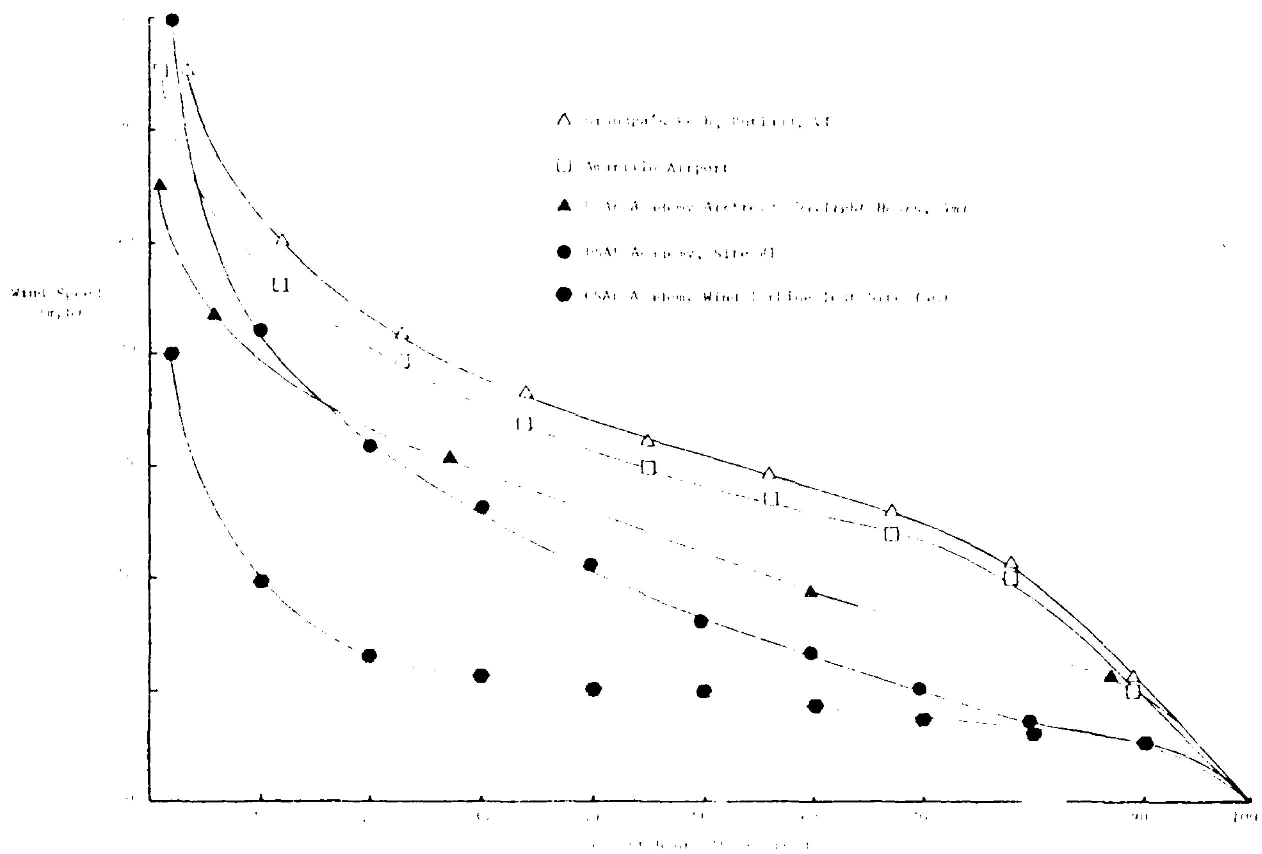



Figure 9. Comparisons of Wind-Speed Duration Curves, 10 Meter Anemometer Heights

TABLE 4: USAFA ECONOMIC ANALYSIS, APPROXIMATE METHOD

I. Annual Fixed Costs as Percent of Initial Cost, $i_1$

| | |
|---|---|
| Cost of Money | 10 % |
| Operations and Maintenance | 2 1/2% |
| | 12 1/2% |

II. Economic Analysis Parameters

| | | Machine | |
|---|---|---|---|
| | | Carter 25 | MOD-2 (2.5 MW) |
| 1. | Cost of System | | |
| | a. System Hardware ($) | 14,500 | 1,545,000 |
| | b. Installation ($) | 3,000 | 725,000 |
| | c. Utility Grid Connection ($) | 2,000 | 230,000 |
| | d. Total System Cost ($) | 19,000 | 2,500,000 |
| | e. Cost per Installed kW ($) | 780 | 1,000 |
| 2. | System Life (Yr) | 20 | 25 |
| 3. | Baseline Electric Cost ($/kW-Hr., 1981) | .025 | .025 |
| 4. | Utility Escalation Rate, $i_2$ (Annual %) | 12% | 12% |
| 5. | Annual Output of Machine (kW-Hr) | 31,700 | 4,913,500 |
| 6. | Annual Value (AV) of Conserved Electricity ($) | 800 | 122,800 |
| 7. | Annual Fixed Cost - Utility Escalation Rate, $(i_1 - i_2)$(%) | 1/2 | 1/2 |
| 8. | Capital Recovery Factor (CRF) $\text{CRF} = \frac{\text{AV}}{\text{Total System Cost}}$ | .041 | .049 |
| 9. | Years-to-Simple-Payback (Compound Interest Table using CRF) | 26 | 21 |
| 10. | Payback Factor (PF) $\text{PF} = \frac{\text{Line 9}}{\text{System Life}}$ | 1.30 | .84 |

TABLE 5: USAFA ECONOMIC ANALYSIS, AIR FORCE METHOD, MODEL 25

| | |
|---|---|
| **Costs** | |
| 1. Total System Costs | $19,500 |
| **Benefits** | |
| 2. Recurring Benefit/Cost Differential Other Than Energy | |
| a. Annual Labor Decrease (+)/Increase (-) | $ -300/Yr |
| b. Annual Material Decrease (+)/Increase (-) | $ -100/Yr |
| c. Other Annual Decrease (+)/Increase (-) | $ -100/Yr |
| d. Total Costs | $ -500/Yr |
| e. 10% Discount Factor (MCP Table) | 8.933 |
| f. Discounted Recurring Cost [2d x 2e] | $-4,500 |
| 3. Recurring Energy Benefit/Costs | |
| a. (1) Annual Energy Decrease (+)/Increase (-) | 368 MBTU/Yr |
| (2) Cost per MBTU | $2.16/MBTU |
| (3) Annual Dollar Decrease (+)/Increase (-) [3a(1) x 3a(2)] | 800/Yr |
| (4) Differential Escalation Rate (12%) Factor | $ 21.69 |
| (5) Discounted Dollar Decrease (+)/Increase (-) [3a(3) x 3a(4)] | $ 17,400 |
| b. Discounted Energy Benefits [3a(5)] | $ 17,400 |
| 4. Total Benefits [2f + 3b] | $ 12,900 |
| 5. Discounted Benefit/Cost Ratio [4 ÷ 1] | .66 |
| 6. Total Annual Energy Savings [3a(1)] | 368 MBTU/Yr |
| 7. E/C Ratio [6 ÷ 1/1000] | 19 MBTU/$1000 |
| 8. Annual $ Savings [2d + 3a(3)] | $ 300 |
| 9. Payback Period [(1 - Salvage) ÷ 8] | 65Yr |
| 10. PF | 3.25 |

TABLE 6: USAFA ECONOMIC ANALYSIS, AIR FORCE METHOD, MOD-2

| | | |
|---|---|---|
| Costs | | |
| 1. | Total System | $2,500,000 |
| Benefits | | |
| 2. | Recurring Benefit/Cost Differential Other Than Savings | |
| | a. Annual Labor Decrease (+)/Increase (-) | $ -37,500/Yr |
| | b. Annual Material Decrease (+)/Increase (-) | -12,500/Yr |
| | c. Other Annual Decrease (+)/Increase (-) | -12,500/Yr |
| | d. Total Cost | $ -62,500/Yr |
| | e. 10% Discount Factor (MCP Table) | 9.524 |
| | f. Discounted Recurring Costs [2d x 2e] | $ -595,300 |
| 3. | Recurring Energy Benefit/Costs | |
| | a. Type of Fuel-Electricity | |
| | (1) Annual Energy Decrease (+)/Increase (-) | 57,000 MBTU/Per Yr |
| | (2) Cost per MBTU | $2.16/MBTU |
| | (3) Annual Dollar Decrease (+)/Increase (-) [3a(1) x 3a(2)] | $ 123,100/Yr |
| | (4) Differential Escalation Rate (12%) Factor | 28.45 |
| | (5) Discounted Dollar Decrease (+)/Increase (-) [3a(3) x 3a(4)] | $3,494,800 |
| | b. Discounted Energy Benefits [3a(5)] | $3,494,800 |
| 4. | Total Benefits [2f + 3b] | $2,899,500 |
| 5. | Discounted Benefit/Cost Ratio [4 ÷ 1] | 1.16 |
| 6. | Total Annual Energy Savings [3a(1)] | 57,000 MBTU/Yr |
| 7. | E/C Ratio [6 ÷ 1/1000] | 22.8 MBTU/$1000 |
| 8 | Annual $ Savings [2d + 3a(3)] | $ 60,000 |
| 9. | Payback Period [(1 - Salvage) ÷ 8] | 42Yr |
| 10. | PF | 1.68 |

## SECTION III

## METHODOLOGIES FOR USAF WIND SITE SURVEYS

### 1. INTRODUCTION

It is important that an Air Force wind program be organized and managed such that the energy available in the wind is utilized in the most efficient and economical manner. The purpose of this chapter is to present three methodologies, each representing a differing lead time to wind machine installation, which can be used to support this goal. These methodologies link a broad range of topics from resource assessment through engineering economics to environmental issues.

It became apparent early in this study that more than one methodology was required. An essential methodology is one dealing with the question of which Air Force base or operating location should receive the first wind machine installation, the second, and so forth, without regard to outside influences such as politics or interest or funding availability in individual commands. The authors strongly recommend this approach, presented as Methodology I, while realizing that other factors may cause bases to be considered on individual merits and outside the constraints of this methodology. The individual base approach is presented in Methodologies II and III.

### 2. ASSUMPTIONS

It is important that assumptions used in all three methodologies be clearly stated and understood before application of the methodologies proceeds. To some the assumptions may appear simplistic and unrealistic. However, the following of an organized methodology is far more important than the specific tools used at each step. As the step-specific tools become more sophisticated, they will simply replace those in current use. Table 7 lists each general assumption with accompanying discussions.

### 3. METHODOLOGY I - AN ORGANIZED USAF-WIDE APPROACH

This methodology is a USAF-wide approach resulting in a rank ordering of all bases and locations from highest to lowest in potential for wind [illegible] installation. This potential is not [illegible]

resource but includes economics, environmental and institutional factors. Figures 10 and 11 show flow charts of Methodology I and Tables 8 and 9 describe the individual steps and loops, respectively. It should be noted that after the overall rank ordering in Step 6, groups of "N" bases are then considered in depth. The magnitude of "N" depends on the level of and time scale over which the program and funding proceed. Realistically, "N" might equal five at program initiation.

4. METHODOLOGY II - THE INDIVIDUAL BASE APPROACH

Methodology II assumes that one specific base or location is being singled out for consideration outside of and separate from the procedure of Methodology I. In addition, Methodology II assumes that one or more years are available for controlled instrumentation and site selection. Figure 12 is a flow chart of Methodology II and Table 10 describes each individual step.

5. METHODOLOGY III - THE INDIVIDUAL BASE APPROACH

Methodology III is similar to Methodology II except that, for whatever reason, a decision to fund and install a wind machine at a particular base is nearly final. Therefore, the 1-to 2-year period for instrumentation does not exist. The goal in this case is to do a rapid and, hopefully, efficient selection of sites for immediate installation of wind machines. Figure 13 shows the flow of Methodology III and Table 11 describes the individual steps.

TABLE 7: ASSUMPTIONS USED IN METHODOLOGIES I, II, AND III

| Assumption | Discussion |
|---|---|
| Wind "quantity" is more important than "quality". | The quantity of wind, reflected as a wind frequency distribution, is necessary for predicting wind turbine power output. Quality of the wind field, measured by such factors as turbulence, will surely affect machine performance yet is not presently measured and available for most locations. As this information becomes available and wind machine manufacturers know how their product responds to quality factors, new calculations should be completed. |
| Wind machines selected for Air Force applications should be fully tested by other government agencies. | Selected wind machines should have completed thorough DOE testing. Power output curves should be those generated during such tests. |
| The travelling site survey team should be capable of addressing all complex wind power issues. | Environmental and institutional issues must be fully understood and the team must be able to competently deal with such complex topics. Techniques of physically locating potential sites must be practiced and applied. |
| All power generated by a wind machines is used on site. | Questions of resale of wind generated power are not considered. 100% of all power produced by wind machines is used to replace that normally purchased at commercial rates. |
| Electrical power is the standard form of energy output. | Electrical power production is the most common form of output and is the sole form considered here. Other applications of wind machines are encouraged, yet care should be exercised to identify the correct value of energy replaced in such cases. |
| The existing wind data base is acceptable for initial calculations. | The USAF Environmental Technical Application Center wind information, along with other data bases, are maintained at or available on request through the Air Force Engineering and Services Center. While this information was not specifically recorded for wind energy purposes, it is presently the best available data. |

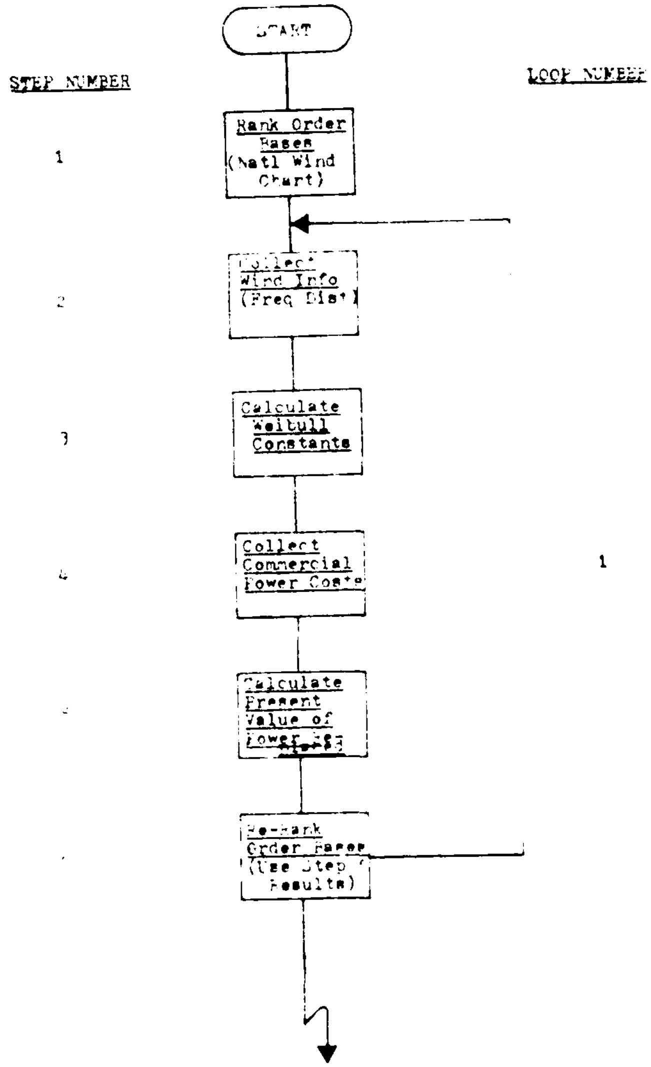



Figure 10. Flow Chart, Methodology I, Steps 1-6

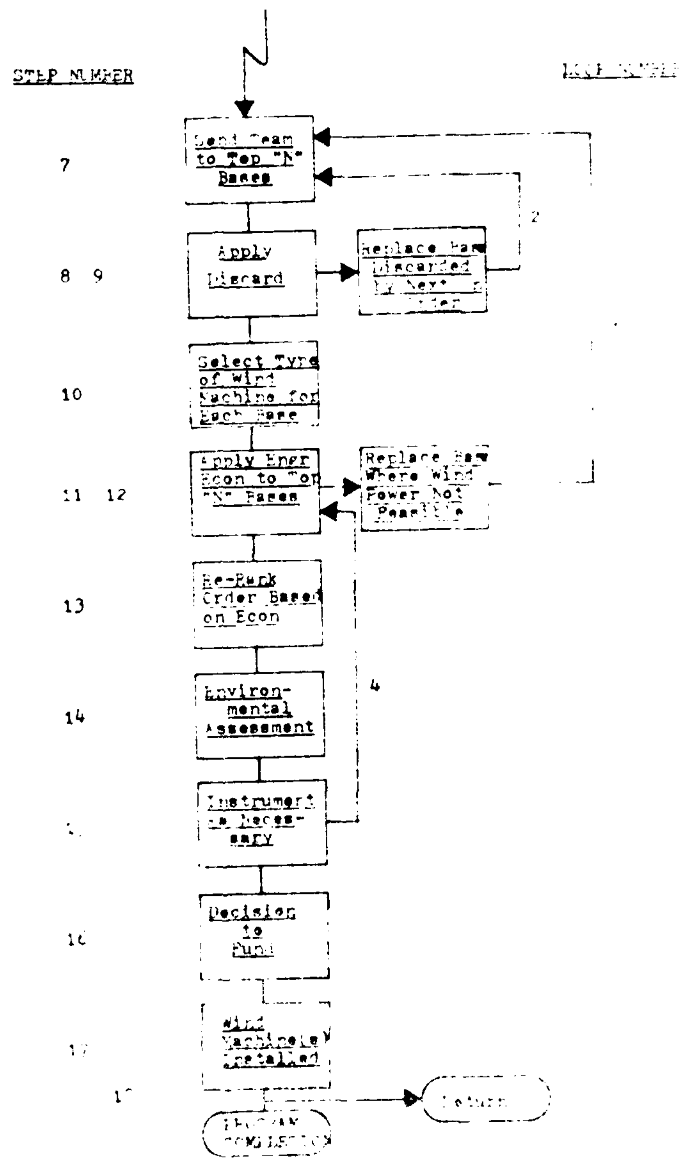



Figure [illegible]
Steps 7-18

TABLE 8: DESCRIPTION OF FLOW CHART STEPS, METHODOLOGY I

| Step Number | Description |
|---|---|
| 1 | Using national maps of wind potential in watts/square meter at a height of 50 meters, locate bases and rank order from the base with the highest wind potential to the lowest. This step has the sole purpose of supplying a simple (but inaccurate) starting point for the methodology. |
| 2 | Collect wind frequency distribution information on each base in the order established in Step 1. Most bases, particularly those with airfields, have rather extensive data bases maintained by government agencies. Much of this data has been reduced to a more useable form for wind power calculations. The most important piece of information is the long term record of wind-speed occurrences which leads to a wind frequency distribution. If base-specific information is not available, then similar data from a nearby civilian location must be used but with much lower confidence. |

| Step Number | Description |
|---|---|
| 3 | At this point, the wind frequency distribution should be described by a mathematical function. The most commonly used is the well-known Weibull distribution, which seems to best describe an actual wind frequency distribution. This step is necessary so that the actual wind characteristics can be used in calculations to follow. In addition, the number of KW-hr/square meter is calculated at this point and each time new data is input to Step 2. |
| 4 | Average present-day costs of commercial energy should be collected for each case. Emphasis should be placed upon the type of energy which wind-generated energy will replace. For example, if the wind machine will most likely be of the electrical generating type, then the current cost of commercial electricity in $/KW-hr or equivalent fuel costs should be collected. The purpose of this step is to introduce the effects of economics at the earliest possible point in the methodology as this is a most important factor in the eventual efficient utilization of wind-generated energy. |

| Step Number | Description |
|---|---|
| 5 | The present value of power replaced by wind-generated power is calculated here. No particular wind machine is selected but rather all of the energy in the wind is assumed to be extractable and usable. It is common knowledge that this is a ridiculous practical assumption, yet, for purposes of early rank ordering it is perfectly reasonable in that wind machine dependence is eliminated and all bases are on equal footing. The specific calculation here is: $(\text{kw-hr/meter}^2) \times (\$/\text{kw-hr}) = \$/\text{meter}^2$ This represents the value to the user of the power replaced by a wind machine having a 1-square meter rotor area if that machine could extract 100 percent of the energy in that base-specific wind field. This simple calculation provides an economic index for comparison. |
| 6 | Using the results of Step 5, all bases are re-rank ordered from the highest value of power replaced ($\$/m^2$) to the lowest. Lack of resource or energy cost information for a particular base should not inhibit continuation of the methodology through the steps to follow. Rather, at some regular interval, Steps 2-6 should be repeated to include new information and to add those bases for which necessary data was not previously available. Additionally, if a "special situation" is discovered whereby an attractive wind potential is highly likely, yet not supported by the data, a decision to instrument such a site would be appropriate here. |

| Step Number | Description |
|---|---|
| 7 | An arbitrary number ("N") of bases can now be selected for more intense consideration. Realistically, this number may well be further divided into worldwide geographic regions or separated by major air commands. In any case, offsite preliminary work can commence. Terrain maps, mission information and maps of physical facilities are some of the tools which might indicate if wind machines are even possible at a particular location. Wind machine energy production can also be estimated for the site. If the location still looks promising, it is time for a siting team to visit. The specific tasks of the team are dealt with in a separate section of this report, yet it must be said here that the team's general charter will be to confirm or refute the offsite calculations. Perhaps even more important, the team will determine if there are any serious barriers to wind machine installation and if more potential might be available through careful siting than was predicted by off[illegible] |
| 8 | The [illegible] unsuitable bases [illegible] applied here. This action is a direct result of [illegible] findings by the travelling team. An example of such a condition might be a base having no available land for machine installation except at locations [illegible] the operational mission. Bases discarded are not permanently removed and will reappear for reconsideration when [illegible] exercised. |

| Step Number | Description |
| --- | --- |
| 9 | When a base is discarded as described in Step 8, the next base in the rank ordering takes its place and the previously ranked "N+1" base is moved to the Nth position. This action takes place through the exercising of Loop 2 and insures that "N" bases are always under serious consideration as candidate sites. |
| 10 | For each of the top "N" locations, the most suitable wind machine is selected to match the wind resource. Necessarily, the subject machines should be those recommended after extensive product testing. |
| 11 | Standard techniques of engineering economics are applied to each base/machine combination in this step. The particulars of the economics should be those presently in use for such studies and should include required parameters used in federally funded projects. The "bottom line" should be some common measure such as years-to-simple-payback by which the top "N" bases can be compared. |

| Step Number | Description |
|---|---|
| 12 | A discard based upon results of the Step 11 economic study is applied here. In a fashion similar to Loop 2, Loop 3 is exercised leading to the addition of the "N+1" base bringing the total number of serious candidate sites back to the "N" level. An example of a base discarded at this point would be one having a low average wind speed (wind speed distribution skewed toward low speeds) but high commercial power costs (high $\$/m^2$) resulting in a high rank order. However, when an existing wind machine is added to the picture, the result might be an extremely long payback since a machine might not exist which can extract power from such low speed winds. As in previous discards, this base would not be dropped from consideration completely. It would continue to reappear for consideration each time Loop 1 is exercised and might eventually be paired with a machine that could extract that site's energy. |
| 13 | Based upon the results of the Step 11 economic studies, the top "N" bases are now rank ordered from lowest to highest payback factor where:<br>Payback Factor = Years-to-Payback ÷ Serviceable Life |
| 14 | Environmental assessments should be completed on [illegible] the top "N" bases [illegible] deemed appropriate at this point. This is a critical area which can stop a wind [illegible] |

| Step Number | Description |
|---|---|
| 15 | Following favorable completion of the Step 14 environmental assessments, site-specific wind instrumentation is selected and installed at as many of the "N" bases as is deemed appropriate. The instrumentation should remain in place for a minimum period of 1 year. During, and in particular following this collection period, Loop 4 is continually being exercised to update the economic studies. Care must be taken to use the most current economic parameters. There well may be "special situation" bases not appearing in the top "N" but which should be instrumented early. An example might be a base with a marginal resource from airfield wind records, yet having complex terrain which indicates a strong potential. Delays associated with waiting for this base to naturally appear in the ranking added to the 1-year instrumentation period could produce a lost opportunity. Therefore, flexibility should be the key to instrumentation decisions. |
| 16 | After this cycle through Loop 4, a decision to fund wind machine installation at one or more of the top "N" bases can be made. |
| 17 | Funding results in subsequent machine installation. |

| Step Number | Description |
|---|---|
| 18 | The methodology may or may not be complete at this point. If all "N" bases have received a predetermined maximum number of wind machines, then a return to Step 2 would be in order with the previously considered "N" bases removed from the rank ordering. If all bases have received consideration and/or machine installations to a feasible maximum, then the entire program is complete and the methodology terminates in Step 19. |

TABLE 9: DISCRIPTION OF FLOW CHART LOOPS, METHODOLOGY I

| Loop Number | Description |
|---|---|
| 1 | Loop Number 1 is designed to provide a continuing update of the rank ordering done in Step 6. New wind frequency data and/or unpredictable commercial energy cost escalations will change the rank ordering. The Step 6 ordering should always be based upon the best and most current data, for it is from this list that the second "N", third "N", etc. bases are chosen. This loop should be exercised no less frequently than annually. |
| 2,3 | Both Loops 2 and 3 serve the same purpose; that of keeping the list of "N" most promising candidate bases filled to the level "N" following discards for reasons of insurmountable institutional obstacles or poor economic indicators. These two loops are exercised any time a base is discarded. |
| 4 | Loop 4 provides a continuing cycle within the "N" selected bases and allows for updated economic studies when wind data from newly installed instrumentation predicts a power potential differing from that estimated earlier. This loop would be exercised after 1 year of wind data collection at each base. The economic analyses of Step 11 will be updated to reflect the most current wind machine performance models. |

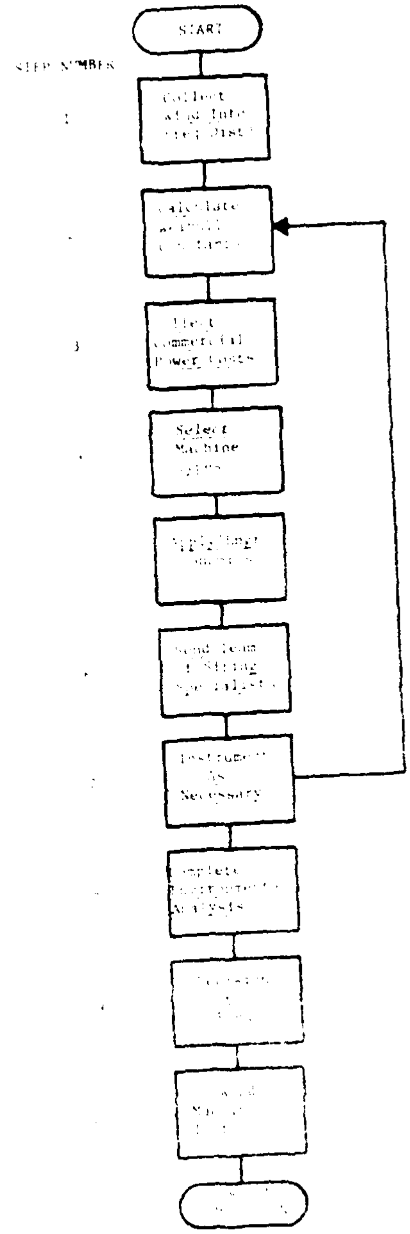


Figure 12. Flow Chart, Methodology II

TABLE 10: DESCRIPTION OF FLOW CHART STEPS, METHODOLOGY II

| Step Number | Description |
|---|---|
| 1 | Collect wind frequency distribution information on the base. (See Step 2, Methodology I) |
| 2 | (See Step 3, Methodology I) |
| 3 | (See Step 4, Methodology I) |
| 4 | Based upon the expected use of the wind-generated power and the estimated machine size and type, pick one or more machines for consideration. Secure power output curves for each of the selected machines. (See Step 10, Methodology I) |
| 5 | Apply standard techniques of engineering economics. (See Step 11, Methodology I) |
| 6 | A travelling team of siting experts travels to the base in question. Specific team tasks are dealt with in a separate section of this report, yet the most important task will be to investigate any serious barriers to wind machine installation and to determine if more potential might be available through careful siting than was predicted by offsite calculations. |

| Step Number | Description |
| --- | --- |
| 7 | Sites (as determined by the travelling team) with estimated potential equal to or greater than predicted by offsite calculations, are instrumented. Instrumentation periods should equal or exceed one year. As site-specific data is obtained, Steps 2-6 are exercised as required and until economic conditions become favorable for wind machine installation. |
| 8 | If Steps 2-6 indicate wind machine installations are viable alternatives, the base environmental coordinator initiates an environmental analysis process. Depending on the extent of the estimated socioeconomic impacts, this step may end with an assessment or be elevated to a higher level, if an in-depth Environmental Impact Statement is required. |
| 9 | Based upon favorable findings from Steps 5, 6, and 8, a decision is made to fund the wind machine project. |
| 10 | Wind machine(s) installed. |

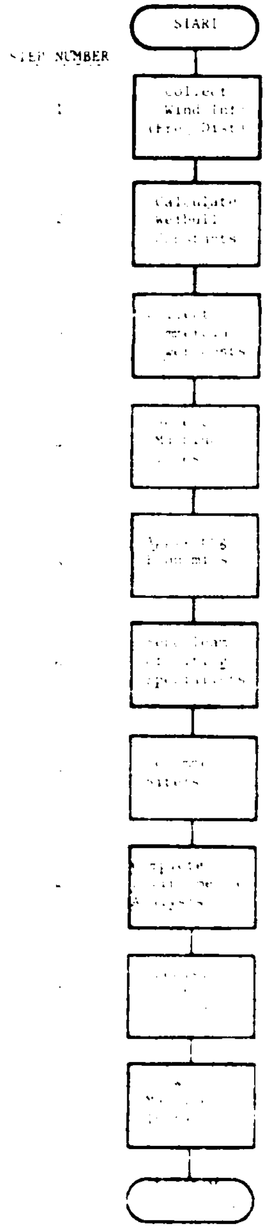



Figure 13. Flow Chart, Methodology III

TABLE 11: DESCRIPTION OF FLOW CHART STEPS, METHODOLOGY III

| Step Number | Description |
|---|---|
| 1-5 | (See Steps 1-5, Methodology II) |
| 6 | Same as Methodology II except that the travelling team directs its efforts toward the immediate answers necessary for a rapid decision on whether to employ wind power. This should be a comprehensive visit, well planned in advance, so that key base personnel are present. Since long-term instrumentation will not be employed, team members must determine the optimum site(s) from limited available data. |
| 7 | Sites selected are for wind machines and not for instrumentation. Selected site(s) should have best possible potential. |
| 8-10 | (See Steps 8-10, Methodology II) |

## 6. INTRODUCTION TO EXAMPLES OF METHODOLOGIES I, II, AND III

Examples using Methodologies I, II, and III are presented in this section. Tables 12, 13, and 14 are keyed to the flow charts and tables of the previous sections and show results using the three methodologies.

The USAF Academy and Vandenberg AFB are the only bases used in the examples, since these are the only two locations for which more or less complete wind site surveying results exist. Due to the limited number of bases considered, the overall impact of Methodology I is lessened, yet, it is particularly important to notice the switch in rank ordering that occurs from Steps 1 to 6. The better wind resource at the USAF Academy is overshadowed by the simple economics introduced in Steps 4 and 5 resulting in Vandenberg AFB taking over the number one ranking. Vandenberg AFB becomes even more firmly entrenched in the number one position (Step 13) following the more detailed economics used in Step 11.

The Methodology II and III examples are keyed to Vandenberg AFB, since this base was actually surveyed using these two methodologies. The examples shown differ only in the recommendations to instrument in the case of Methodology II and to install a wind machine in Methodology III.

TABLE [illegible]: EXAMPLE, METHODOLOGY I

| Step Number | USAF Academy (USAFA) | Vandenberg AFB (VAFB) | Results |
|---|---|---|---|
| 1 | 400 watts/$m^2$ | 200 watts/$m^2$ | Rank Order<br>1. USAFA<br>2. VAFB |
| 2 | Annual frequency distribution from compilator site, 27 April 1979 - 29 April 1980 | Annual frequency distribution from ETAC occurrence summary 1961-1972 | |
| 3 | c = 11.01 (mph)<br>k = 1.30 | c = 8.26 (mph)<br>k = 1.53 | |
| 4 | $.025/kW-hr | $.08/kW-hr | |
| 5 | .0043 $/$m^2$ | .0045 $/$m^2$ | |
| 6 | | | Rank Order<br>1. VAFB<br>2. USAFA |
| 7 | Onsite Inspection | Onsite Inspection | |
| 8 | | | No discard, both bases still have potential |
| 9 | | | Not exercised |

TABLE 10: EXAMPLE, METHODOLOGY I (CONCLUDED)

| Step Number | USAF Academy (USAFA) | Vandenberg AFB (VAFB) | Results |
|---|---|---|---|
| 10 | Carter Model 25 (25 kW rated power) | DOE MOD-2 (2.5 mW rated power) | |
| | Years-to-Simple-Payback | | |
| 11 | Approximate Method: 26<br>Air Force Method: 65 | 15<br>21 | |
| 12 | Replace | Retain | Note: USAFA would be replaced here but is retained for the purpose of this example |
| 13 | Approximate Method: 1.3<br>Air Force Method: 3.25 | 0.6<br>0.84 | Rank Order<br>1. VAFB<br>2. USAFA |
| 14 | Moderate environmental factors | Severe environmental factors (not insurmountable) | |
| 15 | Instrumentation in place, April 1979 | Instrumentation on order | Not available |
| 16 | No decision to fund or install wind machine will be made in this example, yet VAFB seems the most promising of the two sample locations. | | |

TABLE 13: EXAMPLE, METHODOLOGY II

**Step Number** — **Vandenberg AFB (VAFB) Results**

1 ETAC

2. $c$ = 8.26 (mph)

$k$ = 1.53

3 \$.08/kW-hr

4 Carter Model 25 and DOE Mod-2 selected as example machine type

5 Years-to-Simple-Payback

| | Carter 25 | Mod-2 |
|---|---|---|
| Approximate Method: | 19 | 15 |
| Air Force Method | 32 | 21 |

6 Findings:

1. Wind is a viable alternate energy source for VAFB.
2. Much more potential exists than represented by ETAC data.
3. VAFB is "wind data rich", yet the data needs reorganizing into a more useable form.
4. One Mod-2 machine will provide more than 1% electrical energy replacement.
5. Environmental and institutional problems are severe, yet not insurmountable.
6. VAFB is very competitive as a candidate wind machine site.

TABLE 13: EXAMPLE, METHODOLOGY II (CONCLUDED)

| Step Number | Vandenberg AFB (VAFB) Results |
|---|---|
| 7 | Recommendations from Physical Survey, 27-29 July 1980<br>1. Instrument a site just west of Tranquillion Peak.<br>2. Instrument a site near the coast and north of the base proper. |
| 8-10 | Remain to be accomplished. |

TABLE 14: EXAMPLE, METHODOLOGY III

| Step Number | Vandenberg AFB (VAFB) Results |
| --- | --- |
| 1-6 | Same as Methodology II |
| 7 | Recommendations from Physical Survey, 27-29 July 1980<br>Install one Mod-2 type machine at a location just west of Tranquillion Peak. This installation would more than fill the 1985 goal of 1% conventional power replacement by alternative energy sources. |
| 8-10 | Remain to be accomplished. |

## SECTION IV

## SOME WIND SITE SURVEYING TOOLS

### 1. THE WIND SITE SURVEY TEAM

The wind site survey team described in general terms in Steps 7 and 6, Methodologies I, II, and III, respectively, is a key element of the siting approach developed in this report. It is absolutely essential that the three methodologies be supported by individuals highly trained in siting procedures. The team envisioned here is comprised of three individuals whose titles and duties are described in Table 15. A typical onsite inspection is expected to take from 2 to 5 days, depending upon local base support and the level of geographic and environmental complications encountered.

A test of this team concept was accomplished between 27-29 July 1980 at Vandenberg AFB by USAFA personnel. Several weeks of preparation preceded the onsite inspection. Calculations were completed which theoretically linked specific wind machines to the Vandenberg wind field and resulted in prediction of power output. Economic studies leading to years-to-simple-payback were also completed. With this information in hand, the siting team traveled to Vandenberg AFB and spent 1 entire day in meetings with key base personnel and in physical site inspections. The following day concluded with an out-briefing ending in recommendations for continued studies and actions by base personnel which would lead to an organized wind program for that base.

### 2. TALA VERTICAL PROFILING PROCEDURE

The purpose of vertical profiling is to gain some understanding of the wind field in the vertical plane over some site of interest. Vertical profiling with a single TALA system has the major limitation that the wind field changes with time as the profile is taken and the results represent one data point in a phenomena changing with time of day, season, etc. In order to minimize errors associated with this problem, special steps must be employed. The general idea is to take enough time at each altitude to get an accurate time average, yet not so much time that continuity in the wind field is lost. Convenient and recommended reel counts are 75, 150, 300, 600, 1200 and 2400, which yields a profile from about 20 to 220 meters above the selected site. Each reading at a specific reel count takes about

TABLE [illegible]5: WIND SITE SURVEY TEAM COMPOSITION, RESPONSIBILITIES AND DUTIES

| Team Member | Responsibilities and Duties |
| --- | --- |
| Team Chief | 1. Responsible for coordinating the overall siting procedure.<br>2. Supervises the actions of the other two team members.<br>3. Assists the other team members as necessary. |
| Wind Characteristics Specialist | 1. Performs previsit calculations involving the wind field and specific wind machines.<br>2. Prospects for potential high energy density sites.<br>3. Inspects existing instrumentation; recommends new recording devices and their locations. |
| Institutional/Environmental Issues Specialist | 1. Performs previsit data gathering function on possible institutional/environmental problems.<br>2. Performs previsit economic calculations.<br>3. Meets with appropriate base personnel and local community representatives on the broad range of issues in his area of responsibility.<br>4. Determines which, if any, issues will require further study or will preclude wind machine installations. |

five minutes for a total of 30 minutes for the entire profile. Since the kite is already at the maximum altitude at this point, it is recommended that a second set of readings be taken at these same altitudes as the kite is reeled in.

The vertical profiling procedure used at USAFA is listed in Table 16. Specific information regarding operation of TALA is found in (6). Readings are spoken into a tape recorder for a one-person operation or can be written on the form shown in Figure 14 if a second person is involved. The procedure is designed for profiling over a ridge line where readings include inclination of the ridge crest at each kite altitude. Over flat terrain, ridge crest inclination is simply input as zero. Data is then reduced to the form of the Appendix A figures using Computer Program KITPLT of Appendix B.

3. FIXED INSTRUMENTATION

The TALA system just described has a limitation that wind data cannot be recorded over long periods of time. In addition, using only one kite to take a vertical profile introduces uncertainty since the time at each recording level is different. Nevertheless, TALA is a low cost method of obtaining an estimate of vertical shear, yet it should not replace continuous recordings.

Experience gained from the USAFA Wind Site Survey can be used to determine the specifications of fixed instrumentation for other USAF locations in support of the three proposed methodologies. While the equipment installed at the three USAFA sites has performed well, the data set is not complete and was time consuming to access and reduce.

A set of general specifications for a standard wind recording device to support the three methodologies is described in Table 17. The thrust of the specifications is measurement of wind "quantity" (frequency distribution) rather than "quality" (turbulence intensity, gustiness, etc.). "Quantity" measurements are critical for resource assessment but that is not to say that "quality" measurements are never necessary. Once a base is selected as a candidate for a machine installation, "quality" measurements will be a necessary input to the selection of a particular machine. Such measurements are outside the scope of this report. The listed specifications are ambitious and require storage of large data sets. However,

TABLE 16: TALA VERTICAL PROFILING PROCEDURE

1. Assemble reel and handle.
2. Calibrate measuring tube as described in the owner's manual.
3. Remove barometer and thermometer from carrying case and place in a sheltered location. Record temperature and pressure altitude.
4. Read fixed instrumentation if flying over such a site.
5. Launch kite to the first reel count and directly over the selected site.
6. Record start time of the test.
7. Record inclination of the ridgecrest.
8. Record inclination to the kite and wind direction.
9. Record wind speed 10 times with each reading spaced by 15 seconds.
10. Repeat steps 8 and 9 one more time for a total of 20 wind speed readings.
11. Record inclination to the kite and wind direction.
12. Increase reel count for the next set of readings.
13. Return to step 7 and repeat steps 7-12 until the profile is complete.
14. Reel in the kite, again repeating steps 7-12 but now at decreasing reel counts.
15. Take final reading of fixed instrumentation if applicable.
16. Reduce data on a desktop computer or plot by hand.

Location

Temp __________ ($^{o}$F)    Press Alt ______ (ft)    Tail 1, ½    %Cor ____

Time Start ____________________

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Reel Count (N) | | | | | | | |
| - Ridge ($^{o}$) | | | | | | | |
| - Kite ($^{o}$) | | | | | | | |
| Direction | | | | | | | |
| IAS (mph) 1. | | | | | | | |
| 2. | | | | | | | |
| 3. | | | | | | | |
| 4. | | | | | | | |
| 5. | | | | | | | |
| 6. | | | | | | | |
| 7. | | | | | | | |
| 8. | | | | | | | |
| 9. | | | | | | | |
| 10. | | | | | | | |
| - Kite ($^{o}$) | | | | | | | |
| Direction | | | | | | | |
| IAS (mph) 1. | | | | | | | |
| 2. | | | | | | | |
| 3. | | | | | | | |
| 4. | | | | | | | |
| 5. | | | | | | | |
| 6. | | | | | | | |
| 7. | | | | | | | |
| 8. | | | | | | | |
| 9. | | | | | | | |
| 10. | | | | | | | |
| - Kite ($^{o}$) | | | | | | | |
| Direction | | | | | | | |

Time Stop ____________

Direction = Direction + Mag Var (+13$^{o}$) = ____________

$$\text{Alt} = .9(.3N - 2.2 \times 10^{-5}N^2)(\sin \theta_k - \tan \theta_t \cos \theta k) + 10 =$$

TAS = IAS (1 + % Cor) =

Figure 14. Form for Recording Vertical Profiling Data

TABLE 17: PROPOSED WIND RECORDER SPECIFICATIONS

1. Wind speed sampled at 10 meters and 30 meters on a 30-meter tower.

2. Sampled wind speed placed in 1 mph bins at 1-second intervals.

3. Sampling grouped as a frequency distribution covering a 1-hour period resulting in 24 distributions for each of the two recording levels.

4. 48 frequency distributions read to memory monthly.

5. As much data reduction as possible should be carried on internal to the recorder provided the character of the raw data is not destroyed or becomes dependent on a specific wind machine.

6. Capable of self-contained, unattended operation in severe climatic environments for periods exceeding 1 month.

they can always be relaxed at some future date, provided convincing arguments are made which support reduction in data necessary to perform the proposed methodologies.

4. ECONOMIC ANALYSIS

a. Introduction

It is essential that wind power be shown to be economically competitive with other forms of energy. There is no one currently accepted method of evaluating the economics of a wind machine installation. Recent economic studies have ranged from a very basic approach to elaborate methods of life cycle costing which employ statistical analysis. The major differences appear to be in the assumptions made and the number of variables which are included in the analysis. For our methodologies, some simplifying assumptions were made and two contrasting analysis techniques were used.

b. General Assumptions

The following assumptions were applied to both economic analysis methods:

(1) All costs are in 1980 dollars.

(2) Depreciation, insurance and overhead are not siginificant and will not be considered.

(3) No federal or state tax credits are applicable.

(4) System life is the duration specified by the manufacturer.

(5) Discount rate (cost of money) is 10 percent.

(6) All power produced will be used onsite with no sell-back to a utility company.

(7) Operations and maintenance costs are fixed and represent a total annual cost of 2 1/2 percent of initial system cost.

(8) Computer program documented in Section IV,6 and listed in Appendix B are used to estimate wind machine energy production.

c. Approximate Method

This analysis method (7) considers the total annual fixed costs (discount rate = 10%, operations and maintenance = 2 1/2%) as a percentage of the system's initial cost. The annual value (AV) is the amount of power produced by a wind machine multiplied by the current cost of conventional power. A capital recovery factor (CRF) is used to determine years-to-simple-payback. The CRF is computed as: $\mathrm{CRF} = \dfrac{\mathrm{AV}}{\text{Total System Cost}}$.

The interest rate for the CRF is taken as the difference of the annual fixed costs, expressed as percent of system cost, and the utility escalation rate which for the present analyses becomes 1/2%. The payback period is found by using a conventional compound interest for 1/2% and is equal to "n" (number of years) under the CRF factor. For comparing alternative machines with different system lives, a payback factor (PF) can be used where,

$$\mathrm{PF} = \frac{\text{years-to-simple-payback}}{\text{system life}}$$

and the machine with the lowest PF is the most economically attractive.

Although this technique is very simple, it seems to be appropriate when dealing with unproven variables such as machine life, maintenance costs, utility escalation, and general inflation. Some large utilities use a similar approach of computing an equivalent levelized annual cost when operating in an uncertain environment. Table 4 illustrates this method in comparing two machines for potential installation at the United States Air Force Academy.

d. Air Force Method

This analysis method (8) is for a project which falls under the Energy Conservation Investment Program (ECIP) of the Military Construction Program (MCP). Although it was intended primarily for retrofit projects involving alternate fuel sources, it is the method which would probably be used as justification for possible funding.

There are several differences from the approximate method. First maintenance costs (labor and material) must be estimated. As expressed [illegible], wind machine reliability and maintenance requirements [illegible] the impact of a wind machine installation on a typical base maintenance [illegible]

work force can only be guessed. Next, a utility escalation rate is used to compute the benefit/cost ratio, but is not used to calculate the payback period. This results in much longer payback periods which tend to exceed the system life and make wind machines appear economically noncompetitive. A final major difference is that this method requires computation of an energy/cost ratio which must exceed a specified value (20 for FY 81) in order to be approved. This is often difficult to achieve with a new wind machine installation. Tables 5 and 6 illustrate this method for the same wind machines considered with the Approximate Method.

The two methods presented are almost extremes. The Approximate Method can be considered optimistic and the Air Force method extremely conservative. As such, the true payback period is probably bracketed when using the two methods.

5. INSTITUTIONAL ISSUES

a. Introduction

Along with the review of technical wind characteristic data, many other issues must be addressed before a wind machine is installed. This section discusses some of the common nontechnical areas which should be evaluated during a base survey. Table 18 lists these primary institutional issues.

TABLE 18: INSTITUTIONAL ISSUES INVOLVED IN WIND MACHINE SITING

| Natural | Socioeconomic | Other |
|---|---|---|
| Floral/Fauna | Visual Impact | Electromagnetic Interference |
| Noise | Public Concern | Airfield Clear Zones |
| Historical Sites | Zoning | FAA Coordination |
| | Safety | Utility Interface |

b. Environmental Impact

The National Environmental Policy Act of 1969 requires that, before any federal action is taken which could affect the natural or socioeconomic environment, the action's impact must be fully assessed. In the Air Force, environmental assessment ranges from a brief informal review to an extensive

impact statement. In every case, a proposed action's environmental assessment ends with either a negative determination at some level of review or progresses until a Final Environmental Impact Statement is published at the Congressional level.

At a specific Air Force base, the environmental review begins with the Base Environmental Planner preparing an environmental assessment (EA) according to AFR 19-1 and AFR 19-2. In most cases, the EA is then reviewed at major air command level where it is given a negative determination or elevated to a Candidate Environmental Impact Statement.

The Base Environmental Planner should also initiate action for A-95 clearinghouse coordination so that other agencies surrounding the base are aware of the proposed wind machine installation and have the opportunity to comment.

If a proposed installation is of large scope, such as a wind farm, or if environmental impact is evident, the use of the Environmental Technical Information System (ETIS) may assist greatly in the assessment process. The ETIS computerized system, along with the site-specific inputs, can produce a complete assessment in a short period of time.

c. Discussion of Some Important Institutional Issues

(1) Noise

Some of the earlier DOE large wind machines experienced noise problems. Current research indicates that noise is not a problem for small machines and advanced technology will hopefully eliminate this problem for large machines as well.

(2) Electromagnetic Interference

Most of the research thus far has been directed at TV interference. It is known that the upper UHF channels are particularly susceptible to wind machine-induced interference. Research is continuing in order to [illegible] effects on other frequencies and transmission modes. For DOD, it is [illegible] important to ascertain possible interference with radar, microwave, telemetry and other communication and data transmission systems. The DOD Electromagnetic Compatibility Analysis Center, located in Annapolis,

Maryland, is the DOD center for problems pertaining to electromagnetic interference. They are working to evaluate electromagnetic interference caused by wind machines.

(3) Airfield Clear Zones

The Base Siting Specialist must carefully check a proposed wind machine site to insure that Clear Zone criteria are met. This is more of a concern for large wind machines with hub heights greater than [illegible] feet. Coordination with local FAA officials will also be necessary. Any local zoning restrictions, as with government leased land, must also be considered.

(4) Flora/Fauna

Impacts on vegetation and animal life must be assessed. Of particular concern is the presence of endangered species which could restrict wind machine siting.

(5) Historical Sites

The Historic Preservation Act of 1966 protects historic sites from modification. Though not a problem for most bases, Vandenberg AFB, for example, has over 400 reported archaeological sites which cannot be disturbed. This factor, as with endangered species, can further limit wind machine siting on federal installations.

(6) Utility Interface

If a wind machine (or machines) is to be tied into the existing utility grid, a formal agreement with the supplying utility company must be obtained. Items such as connection charge, back-feed protection, and sell-back rate structure must be resolved. It should be noted that poor site selection could result in power more costly than from conventional sources, if the demand rate increases and a low sell-back rate results from the grid connection. Such an instance might be a facility requiring backup power 24 hours per day and operational for only 8 hours with much of the wind power fed into the utility network. The end use of the wind machine installation is, therefore, a most important decision.

(7) Public Concern

Most of the reaction to wind machines has been positive. People recognize the need for alternatives to fossil fuels and in general voice no objection to wind machines, with the possible exception of noise. Safety is also of primary concern in any energy-producing process and product testing actively underway by Rocky Flats, DOE, and other agencies will hopefully address this question.

## 6. DESKTOP COMPUTER PROGRAMS

### a. Introduction

The desktop computer programs described in this section are designed to support the methodologies of Section III. Programs are described here and program listings and sample outputs are shown in Appendix B. All programs are written in BASIC language and listings shown are peculiar to the HP 85 desktop computer. Similar programs are available for the HP 9830, HP 9831, HP 9835 and can be easily adapted to the HP System 45. Users should have the appropriate computer manuals at hand when running these programs.

### b. PROGRAM "CKETAC"

The Weibull distribution is frequently used to model actual wind speed frequency distributions. Use of such a model allows a lengthy data set to be described by two parameters, c and k, where c is called the scale factor and k the shape factor. A probability density function, p(V), can be defined as the probability per unit speed interval at speed V.

$$p(V)dV = (k/c)(V/c)^{k-1}\exp[-(V/c)^{k}]dV$$

The cumulative probability function or wind speed duration curve is then

$$p(V<V_x) = \int_0^{V_x} p(V)dV = 1 - \exp[-(V_x/c)^k].$$

The values of c and k are estimated using an actual wind speed distribution summary, in this case one provided by the USAF Environmental Technical Applications Center (ETAC), and a best least squares fit procedure described [illegible], (9). The [illegible] necessary [illegible] this program may be [illegible]

manually or read from tape. If input manually, the program will allow the operator to store the data to preclude having to reinput the data if more calculations are needed later. The program requires a number of occurrences for each wind speed measured in knots. It computes average wind speed and the Weibull constants, c and k, starting at 1 knot and continuing to 45 knots or the highest velocity for which an occurrence has been observed. The operator has the option of changing these limits to get a better fit of the distribution to the actual data. Video displays and hardcopies of percent time at speed and percent time above speed are produced,along with correlation coefficients.

Input: IF INPUT MANUALLY -

Data location (where data was collected)

Period of data (when it was collected)

Number of occurrences for velocities from 0 to 45 kts

Name of data storage file (if required)

IF INPUT FROM TAPE -

The name of the data file

IF c AND k ARE KNOWN

c (mph), k

Output:

Average wind speed

c (mph), k

Mean, standard deviation and correlation coefficients for Weibull curve fit

Hardcopy:

Tables of speeds, number of occurrences, percent time at and above speed

Average wind speed (mph and knots)

Wind speed range for Weibull fit

Mean, standard deviation and correlation coefficients for Weibull curve fit

Graphs of percent time at and above speed

c. PROGRAM "CKCOMP"

This program computes the Weibull parameters, c and k, as described from Program "CKETAC", using occurrences from a wind speed compilator. The compilator supplies data from eight different wind directions in 32 2-mile per hour increments from 0 to 64 miles per hour. The program computes c and k from 15 to 63 mph or the highest speed for which an occurrence has been observed. Graphs with the actual data points and with the curve defined by the Weibull constants are plotted to help the operator to decide on the quality of the fit. It is possible to compute c and k for limits other than 15 to 63 mph by inputing different limits when cued by the program.

Input: IF INPUT MANUALLY -

Data location

Period of data

Number of occurrences for eight directions and 2 mph increments

Name of data storage file (if required)

IF INPUT FROM TAPE -

The name of the data file

IF c AND k ARE KNOWN -

c (mph), k

Output:

Same as "CKETAC"

Hardcopy:

Same as "CKETAC": EXCEPT the units on the wind speeds between which c and k are computed will be miles per hour

d. PROGRAM "WEIPOW"

This program computes the total power density, in watts per square meter, available in a wind speed distribution described by Weibull parameters c and k. The power density calculated is not that expected from a wind machine, but rather that available in the wind if 100% could be extracted. The Weibull probability is calculated for each wind speed, multiplied by that wind speed cubed, and then converted to the proper units and summed.

Input:

Weibull constants, c (mph), k

Output:

Power in the wind (watts per square meter)

Hardcopy:

c, k, and power

e. PROGRAM "CHGHT"

This program extrapolates Weibull parameters, $c_1$ and $k_1$, from one height, $z_1$, to a second height, $z_2$. The Weibull parameters, $c_2$ and $k_2$, at height $z_2$ can be estimated by the following empirical relations suggested by Justus, et al, (9).

$$c_2 = c_1 \; (z_2/z_1)^n$$

$$k_2 = k_1[1-0.088\ln(z_1/10)]/[1-0.088\ln(z_2/10)]$$

where $$n = [0.37 - 0.088\ln c_1]/[1-0.088\ln(z_1/10)]$$

These relationships are thought applicable for $z_2 < 100$ meters in relatively flat terrain and over a fairly wide range of surface roughnesses.

Input:

Weibull constants, c (m/sec), k

Height at which c and k were computed (meters)

Height for which new values of c and k are desired (meters)

Output:

Weibull constants for new height

Hardcopy:

Original c and k

Original height

New c and k

New height

f. PROGRAM "WINDE1"

This program models a wind machine operating in a specific wind regime described by Weibull parameters c and k. If the wind speed probability distribution p(V) is known and the output power of a wind machine as a function of wind speed is given by P(V), then the average output power of the machine in this wind regime is

$$\bar{P} = \int_0^\infty P(V)p(V)dV.$$

The model used here for the output power of a wind machine as a function of wind speed is shown in Figure 15. Mathematically, this function is:

$$P(V) = \begin{cases} 0 & V \leq V_i \\ P_r(A+BV+CV^2) & V_i < V \leq V_r \\ P_r & V_r < V \leq V_o \\ 0 & V > V_o \end{cases}$$

where V is the wind speed at the hub height of the wind machine. $P_r$ is its rated power and A, B and C are coefficients determined internally to the program as described by Justus, et al, (9). $V_i$ is the cut-in wind speed of the wind machine, $V_r$ is the speed at which the machine reaches rated power and $V_o$ is the cut-out or shutdown speed of the machine. The annual energy output of the machine is then

$$\bar{E} = 8760 \times \bar{P} .$$

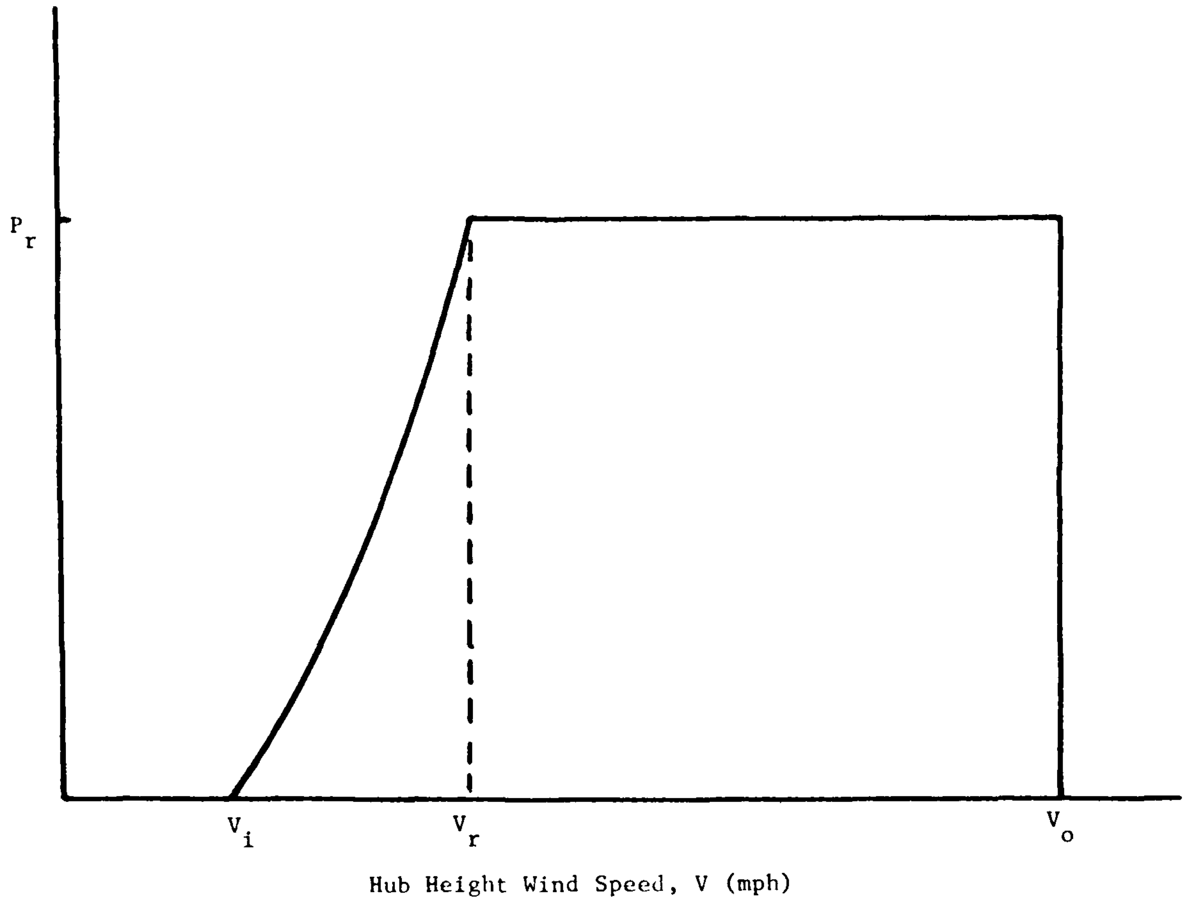



Figure 15.  Wind Machine Power Output Model

A common measure of wind machine performance at a specific site is the capacity factor, $C_f$, which is the ratio of the actual average power output to the rated power of the wind machine.

$$C_f = \bar{P}/P_r \ .$$

Another common measure of wind machine performance is called the recovery factor, $R_f$. This factor is a ratio of the annual energy output of the wind machine to the total energy that was available in the wind,

$$R_f = \bar{E} \ / \int_0^\infty (1/2 \rho A_s V^3) p(V) dV$$

where $A_s$ is the swept area of the wind machine rotor and $\rho$ is the air density.

Input:

- Cut-in wind speed, $V_i$, (mph)
- Rated wind speed, $V_r$, (mph)
- Cut-out wind speed, $V_o$, (mph)
- Number of 1 mph intervals, cut-in speed to rated speed
- Wind turbine rated power (kW)
- Wind turbine rotor diameter (feet)
- Site elevation above sea level (feet)
- Weibull constants c and k (c in mph)
- Number of hours considered (usually 8760 for one year)
- Commercial electric costs ($/kW-hr)

Output:

- Wind turbine swept area ($ft^2$)
- Average wind speed (mph)
- Average power output (kW)
- Capacity factor, $C_f$
- Energy output, $\bar{E}$ (kW-hr for the period of time considered)
- Recovery factor, $R_f$
- Dollars per square meter (value of the commercial power replaced by power produced from one square meter of wind turbine area)

Hardcopy:

- Same as input and output

g. PROGRAM "WINDE2"

This program performs the same function as WINDE1 except here the wind machine power output curve, P(V), is described by a polynomial of degree n. Some wind machines display a power output which cannot be modeled as shown in Figure 15. WINDE2 uses Simpson's Rule to numerically integrate the product of wind frequency distribution (described by Weibull parameters c and k) and the wind machine power output curve, P(V), where

$$P(V) = a_o + a_1 V + a_2 V^2 \ldots a_n V^n .$$

The user must independently generate the coefficients $a_o \ldots a_n$ for a best fit of the actual power output curve. Many routines, such as least squares fit, are readily available for this purpose.

Input:

- Cut-in wind speed (mph)
- Cut-out wind speed (mph)
- Weibull constants, c and k (c in mph)
- Wind turbine rated power (kW)
- Wind turbine rotor diameter (feet)
- Site elevation above sea level (feet)
- Number of hours considered (usually 8760 for 1 year)
- Number of polynomial coefficients to describe wind turbine power curve, n + 1
- Values of polynomial coefficients, $a_o \ldots a_n$
- Integration steps (even number - cut-out speed minus cut-in wind speed)
- Commercial electric costs ($/kW-hr)

Output:

- Average wind speed (mph)
- Energy output (kW-hr)
- Capacity factor, $C_f$
- Recovery factor, $R_f$
- Dollars per square meter (value of the commercial power replaced by power produced from one square meter of wind turbine area)

Hardcopy:

- Same input and output

## SECTION V

## CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

a. USAFA Wind Site Survey

Results of the wind site survey of the USAF Academy indicate a moderate wind potential with indications of more potential, perhaps even that of a "good" site, at elevations above 30 meters on ridge line sites #1 and #2. However, economic analyses using the Site #1 results showed long payback periods primarily due to low present costs of electrical power. Based upon these results, wind machine installations at USAFA are not currently cost effective. However, better definition of ridge speedup effects, coupled with future unforeseen commercial power cost escalation, could well drive the Air Force Academy to a more competitive position. In addition, and perhaps of more importance, wind site survey techniques developed at USAFA can be applied to similar surveys at other Air Force bases.

b. Wind Site Survey Methodologies for USAF Bases

Tests of the three methodologies presented in this report indicate they can be successfully used to support USAF inputs to the federal applications study required in the Wind Energy Systems Act of 1980. However, the Air Force Method of economic analysis does not adequately support the methodologies due to omission of utility escalation rates when calculating years-to-simple-payback.

2. RECOMMENDATIONS

a. USAFA Wind Site Survey

To produce a more complete set of wind characteristics for USAFA, one or two 30-meter towers equipped with instrumentation suggested in Section IV. 3. should be installed at ridge line sites. As this information becomes available, and/or commercial power costs escalate at a higher rate than assumed in this report, new economic calculations should be completed.

b. Wind Site Survey Methodologies for USAF Bases

Methodology I should be applied to a rank ordering of all USAF bases in support of the federal applications study. Methodologies II and III should also be used where appropriate. The economic analysis referred to in this report as the Air Force Method should be revised to more adequately support funding for wind machine installations anticipated under the direct federal procurement provisions of the Wind Energy Systems Act of 1980.

## REFERENCES


1. Kullgren, T.E., and Wiedemier, D.W., Final Technical Report on the USAFA Vertical Axis Wind Turbine, ESL-TR-80-48, Air Force Engineering and Services Center, Tyndall AFB, Florida, September 1980.

2. Public Law 96-345, Wind Energy Systems Act of 1980, 96th Congress of the United States, September 8, 1980.

3. Lofgren, S.T., USAFA Wind Site Survey, Final Report, CE499, USAF Academy, Colorado, May 1978.

4. Meroney, R.N, Sandborn, V.A., Bouwmeester, R.J.B., and Rider, M.A., Sites for Wind Power Installation: Wind Tunnel Simulation of the Influences of Two-Dimensional Ridges on Wind Speed and Turbulence, NSF/RANN GAER 75-00702 Annual Report: First Year, Colorado State University, July 1976.

5. Garstang, M., and Snow, J.W., Testing of the TALA Kite-Anemometer, Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia 22903, December 1977.

6. Instructions for Hand-held Wind Measuring Device, Tethered Aerodynamic Lifting Anemometer (TALA). Approach Fish, Inc., 314 Jefferson St., Clifton Forge, Virginia 24422.

7. Gipe, P., "Estimating WECS Costs," Wind Power Digest, Fall 1979.

8. "FY1980-FY1985 Military Construction Program (MCP) Guidance No. 1," HQUSAF PRE Letter, 24 January 1978.

9. Justus, C.G., Hargraves, W.R., and Mikhail, A., Reference Wind Speed Distributions and Height Profiles for Wind Turbine Design and Performance Evaluation Applications, ERDA Technical Report, Contract No. E(40-1)-5108, August 1976.

10. Orgill, M.M., Huang, C., and Drake, R.L., An Interim Handbook for Siting Large Wind Energy Conversion Systems (Draft), Battelle Pacific Northwest Laboratories, Richland, Washington, July 1977.

## APPENDIX A

## USAFA WIND SITE SURVEY RESULTS TABLES AND FIGURES

### 1. USAFA WIND TURBINE TEST SITE

Tables A-1 through A-5 and Figures A-1 through A-24 show tabulated annual and seasonal wind characteristics for the USAF Academy Wind Turbine Test Site (USAFA WECS Site). Tables A-1 through A-5 show wind speed versus direction where each column represents occurrences in the 2 mph increment below that speed. Figures A-15 through A-24 show wind direction variations for time of day. All tables and figures were produced from strip chart data reduced using the digitizing capabilities of an HP-9830 desktop computer. Missing time periods represent downtime on the WECS Site wind data recorder.

### 2. USAFA COMPILATOR SITE

Tables A-6 through A-10 and Figures A-25 through A-39 show tabulated annual and seasonal wind characteristics for Site #1, called the USAFA Compilator Site. Tables A-6 through A-10 list wind speed occurrences at 1- second intervals for 32 2 mph speed bins versus eight magnetic wind directions. Included on the figures are Weibull coefficients for curve fits to the percent time above speed data. The reliability of data shown for summer and fall 1979 is questionable. During this period, the wind direction head malfunctioned due to a manufacturing defect later corrected by the supplier.

### 3. TALA FLIGHT RECORDS

Figures A-40 through A-51 show vertical wind speed and direction profiles from flights of the TALA anemometer above Sites #1, #2, and #3. Site #1 is referred to on the figures as the Compilator Site, while Sites #2 and #3 are referred to as the North and South Accumulators, respectively. Data points for 10 meters are those taken from fixed instrumentation at those sites.

[illegible] A-1: WIND [illegible] VS. DIRECTION, USAFA WECS SITE, SPRING 1978

[illegible] WIND [illegible] WECS SITE

| DIRECTION | 6 | 8 | 1[illegible] | 1[illegible] | [illegible] | 16 | 18 | [illegible] | 2[illegible] | 4 | [illegible] | [illegible] | 30 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | [illegible] | 10 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | [illegible] | [illegible] | [illegible] | 0 | 0 | [illegible] |
| 20 | 30 | [illegible] | [illegible] | 0 | [illegible] | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | [illegible] | 6 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 |
| 60 | 45 | 15 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 80 | [illegible] | 11 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 3 | [illegible] | [illegible] | 1 | 0 |
| 00 | 10[illegible] | 19 | [illegible] | 1 | [illegible] | 0 | 0 | 0 | [illegible] | 0 | 0 | [illegible] | 0 | 0 |
| 20 | 15[illegible] | 3[illegible] | 2[illegible] | [illegible] | [illegible] | 1 | 0 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | [illegible]5 | 6 | 2 | 4 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | 0 | 0 | 0 |
| 80 | 49 | [illegible] | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | 0 | 0 | 0 |
| 00 | 27 | [illegible] | [illegible] | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 51 | 4 | [illegible] | [illegible] | 1 | 1 | 1 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 4[illegible] | [illegible] | 1[illegible] | [illegible] | [illegible] | [illegible] | 15 | 11 | [illegible] | 4 | [illegible] | 0 | 0 | 0 |
| 60 | [illegible] | [illegible]0 | 11 | [illegible] | [illegible] | [illegible] | 1 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | [illegible] | 10 | 4 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 00 | [illegible] | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 320 | 1[illegible]6 | 6 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | 0 | 0 | 0 |
| 340 | [illegible] | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| TOTALS | 1[illegible] | 165 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

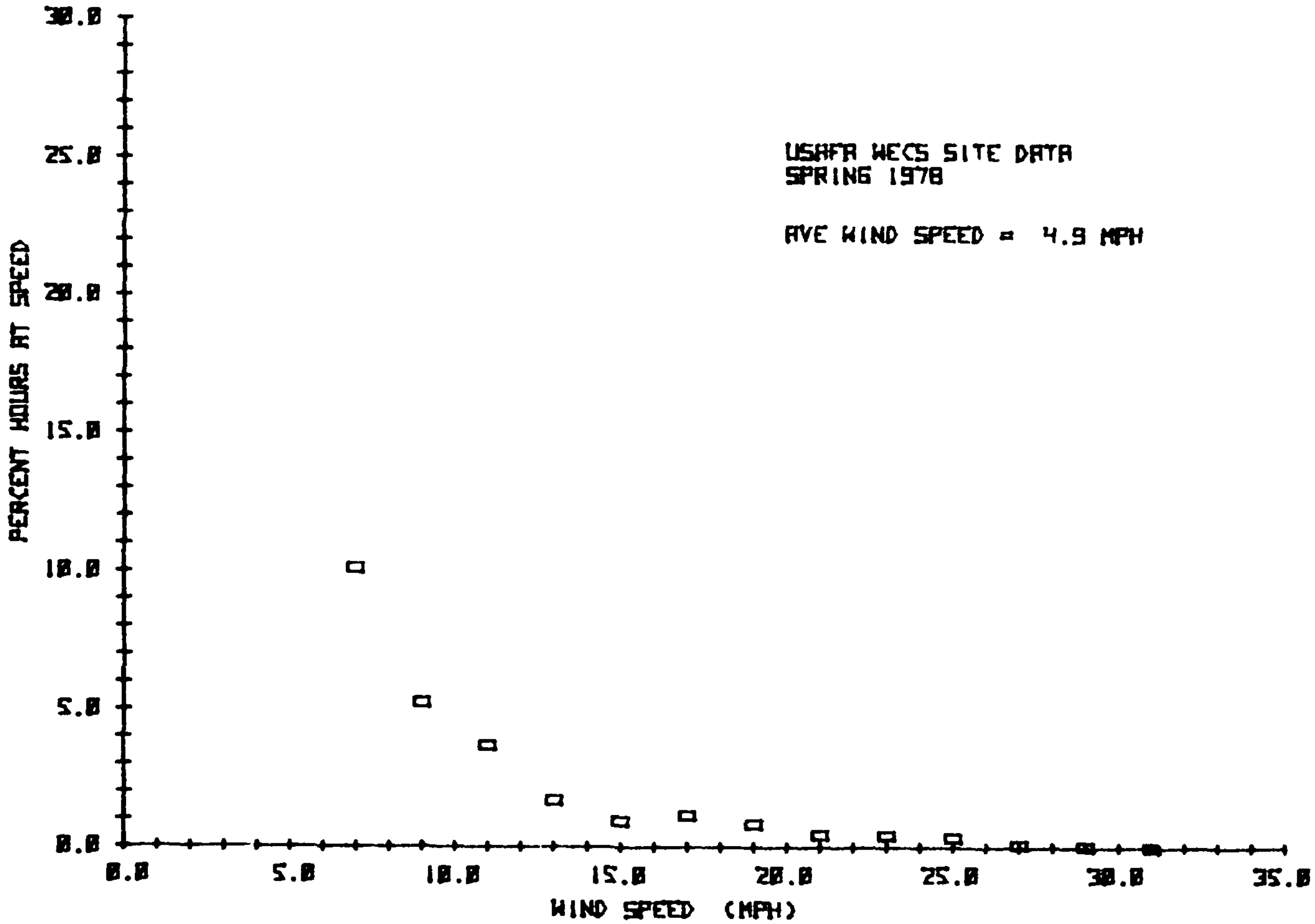



Figure A-1. Percent Hours at Speed, USAFA WECS Site, Spring 1978

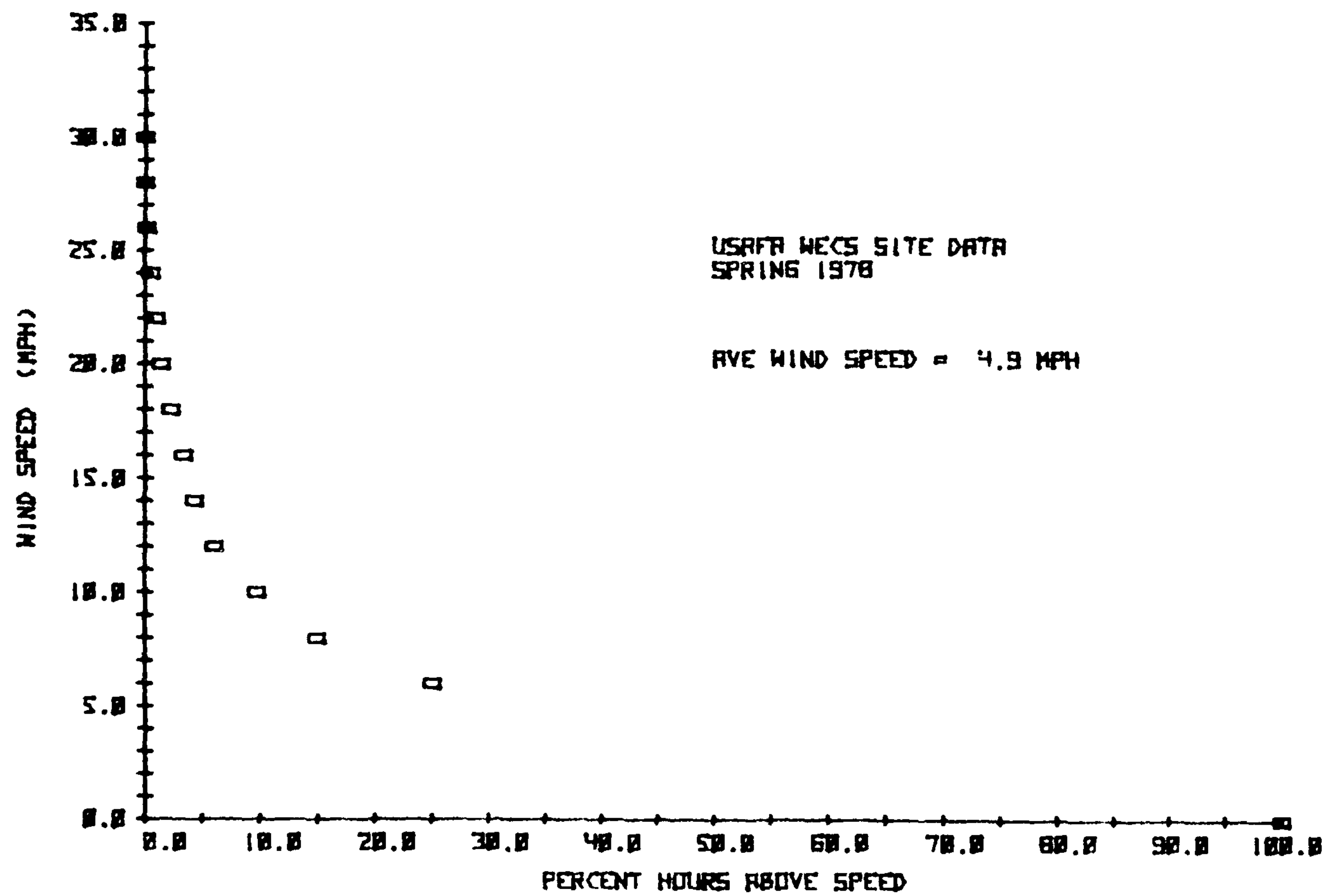



Figure A-2. Percent Hours Above Speed, USAFA WECS Site, Spring 1978

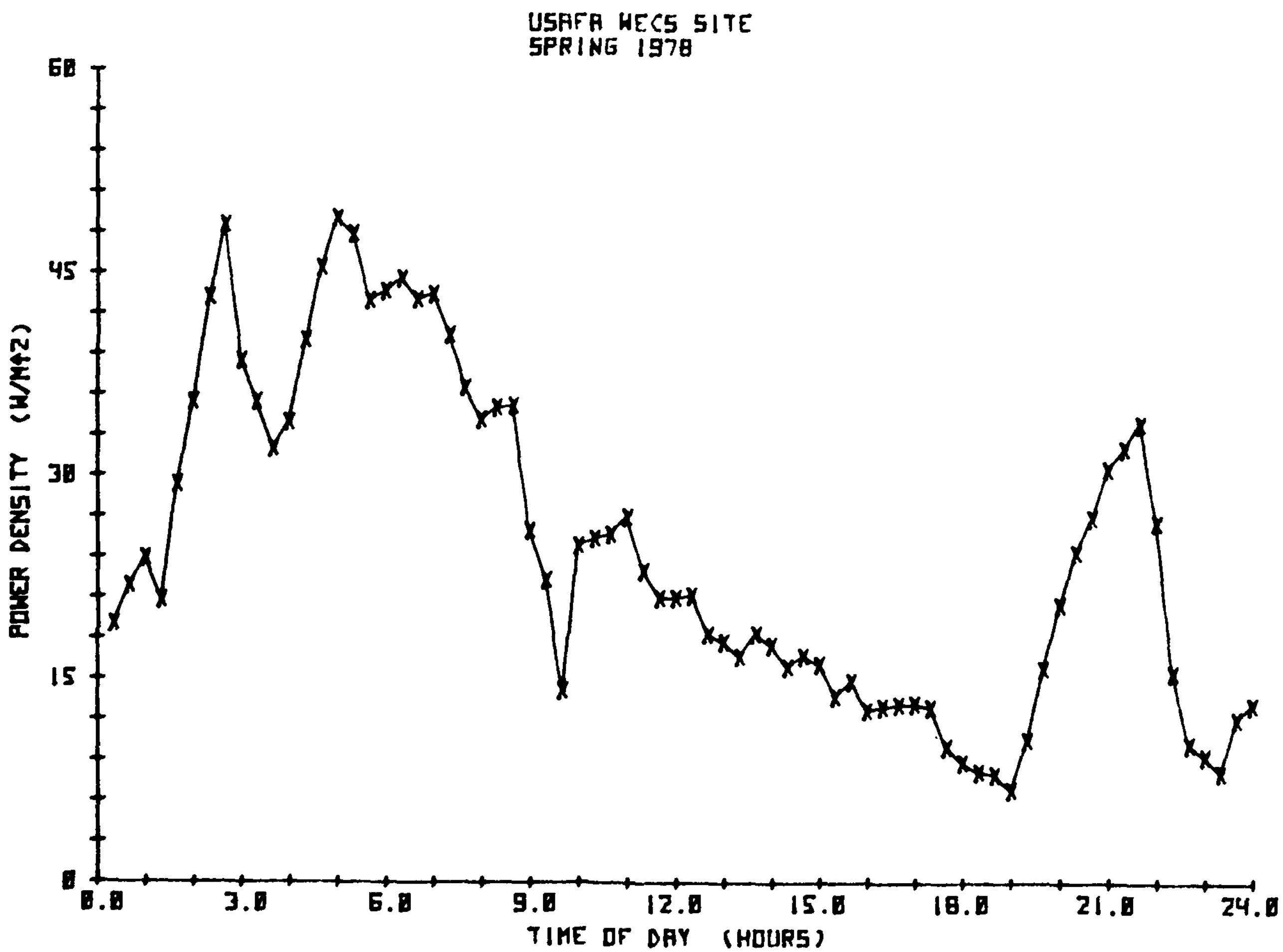



Figure A-3. Power Density,
USAFA WECS Site, Spring 1978

TABLE A-2: WIND SPEED OCCURRENCE VS. DIRECTION, USAFA WECS SITE, SUMMER 1978

| DIRECTION | <6 | <8 | <10 | [illegible] | [illegible] | [illegible] | [illegible] | <20 | [illegible] | [illegible] | [illegible] | <28 | <30 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 33 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 41 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 35 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 28 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | 36 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 46 | 11 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120 | 98 | 49 | 37 | 21 | 12 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 140 | 157 | 45 | 25 | 4 | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 160 | 130 | 11 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180 | 72 | 7 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200 | 62 | 11 | 1 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 220 | 43 | 12 | 7 | 3 | 4 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 240 | 50 | 15 | 13 | 11 | 16 | 10 | 1 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 |
| 260 | 49 | 18 | 13 | [illegible] | 11 | [illegible] | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 |
| 280 | 59 | 10 | 5 | 1 | 1 | [illegible] | [illegible] | 0 | [illegible] | 0 | [illegible] | [illegible] | 0 | 0 |
| 300 | 71 | 8 | [illegible] | 1 | 0 | [illegible] | [illegible] | 0 | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 |
| 320 | 82 | 7 | [illegible] | [illegible] | 0 | [illegible] | [illegible] | 0 | [illegible] | 0 | [illegible] | 0 | 0 | 0 |
| 340 | 54 | 14 | 1 | [illegible] | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 | 0 |
| TOTALS | 1157 | 238 | 12[illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 |

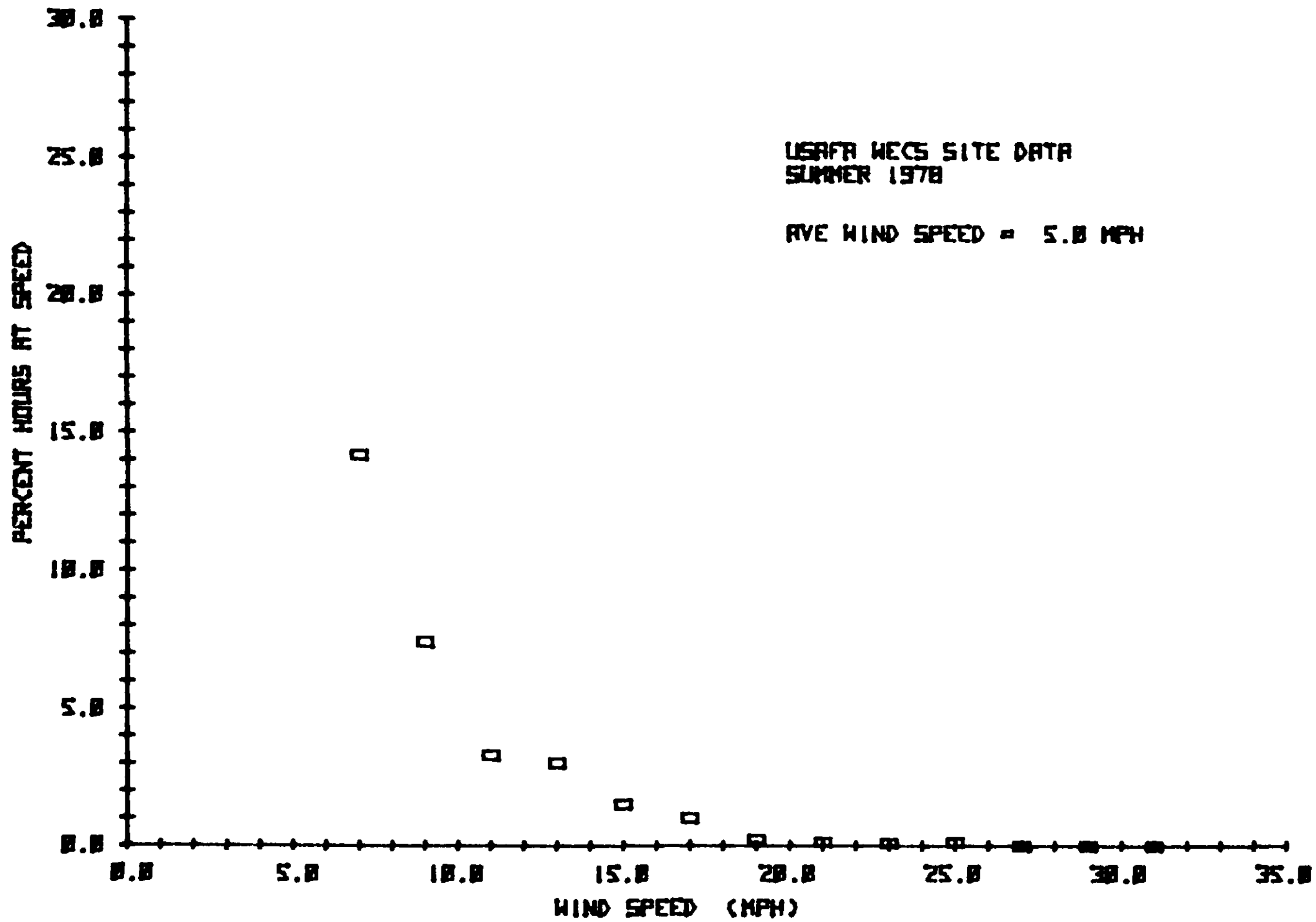



Figure A-4. Percent Hours at Speed,
USAFA WECS Site, Summer 1978

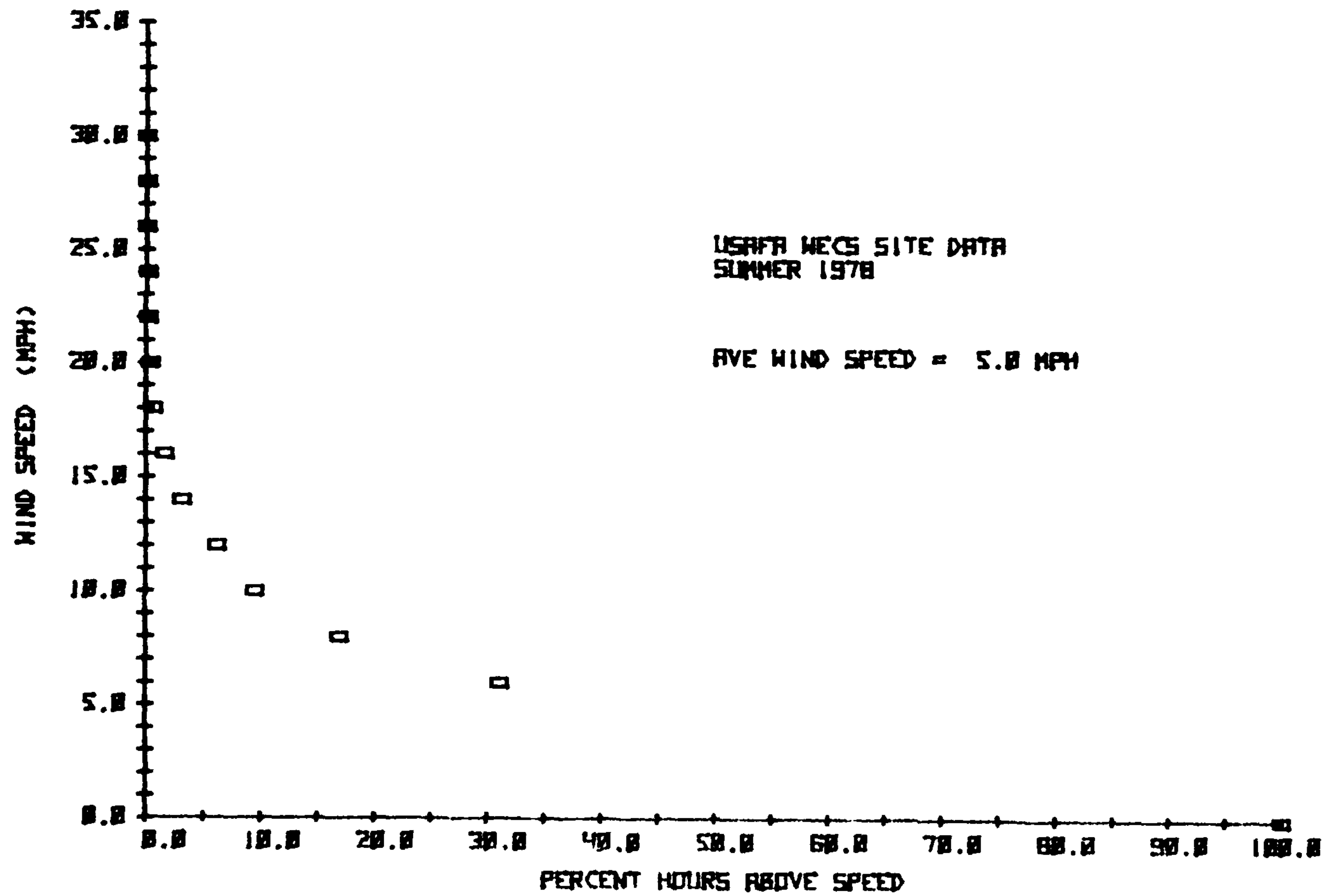



Figure A-5. Percent Hours Above Speed,
USAFA WECS Site, Summer 1978

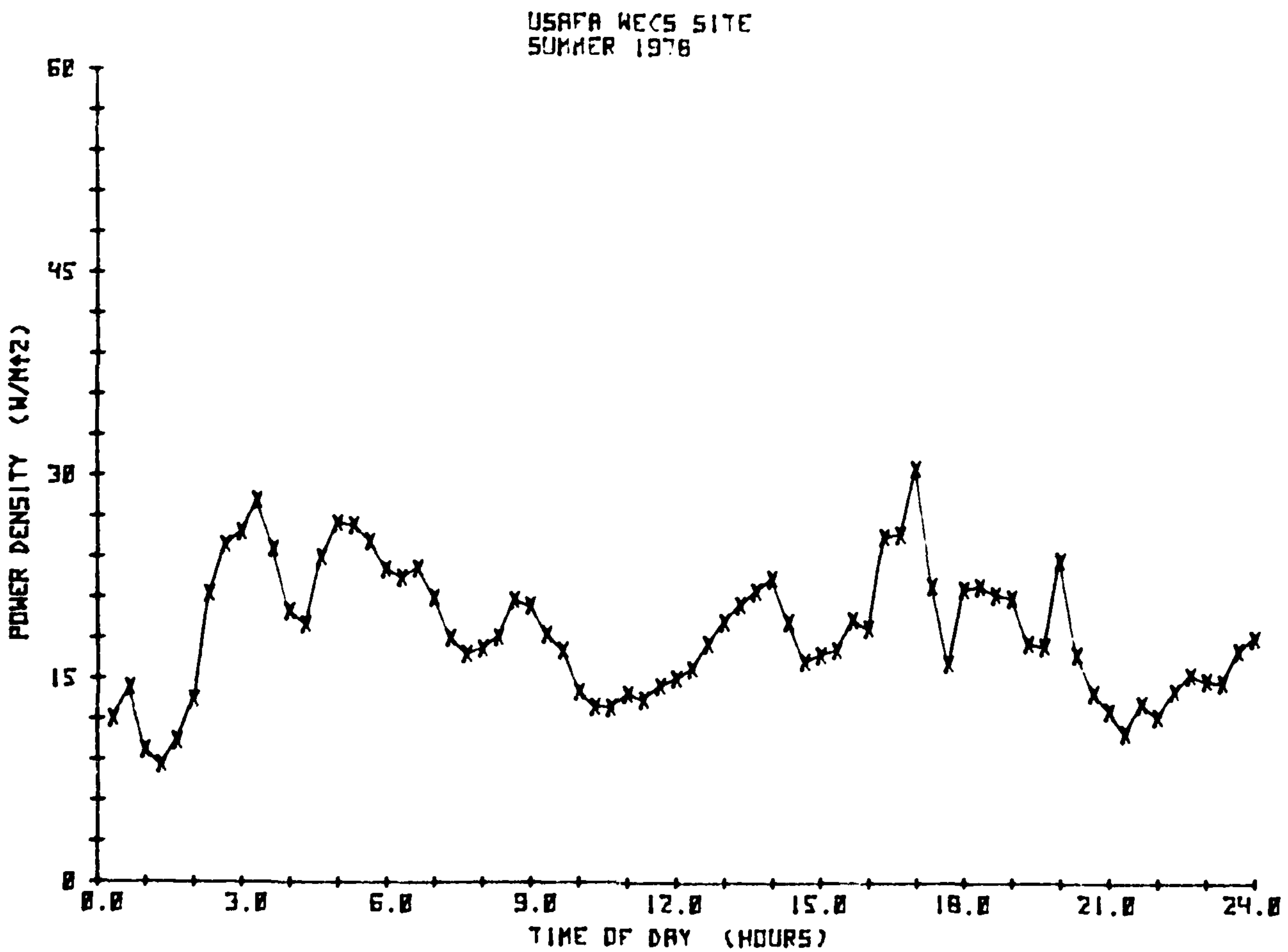



Figure A-6. Power Density,
USAFA WECS Site, Summer 1978

TABLE A-4: WIND SPEED OCCURRENCE VS. DIRECTION, USAFA WECS SITE, FALL 1978

THE FOLLOWING DATA ARE BEING COLLECTED:
FALL 1978 USAFA WECS SITE

| DIRECTION | VELOCITY 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 18 | 0 | [illegible] | 0 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 19 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 21 | 1 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 24 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | 33 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 59 | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120 | 211 | 104 | 53 | 15 | [illegible] | [illegible] | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 140 | 247 | 51 | [illegible] | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 160 | 134 | 6 | [illegible] | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180 | 77 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200 | 65 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 220 | 53 | 7 | 3 | [illegible] | [illegible] | 1 | 0 | 0 | 0 | 0 | [illegible] | 0 | 0 | 0 |
| 240 | 71 | 11 | 22 | [illegible] | [illegible] | [illegible] | [illegible] | 6 | 2 | [illegible] | [illegible] | 3 | [illegible] | 0 |
| 260 | 73 | 16 | 17 | 11 | [illegible] | [illegible] | [illegible] | [illegible] | 1 | 0 | [illegible] | 0 | 0 | 0 |
| 280 | 83 | 5 | [illegible] | [illegible] | [illegible] | 0 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 300 | 117 | 5 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 320 | 178 | 10 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 340 | 116 | 16 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTALS | [illegible] | 243 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0 |

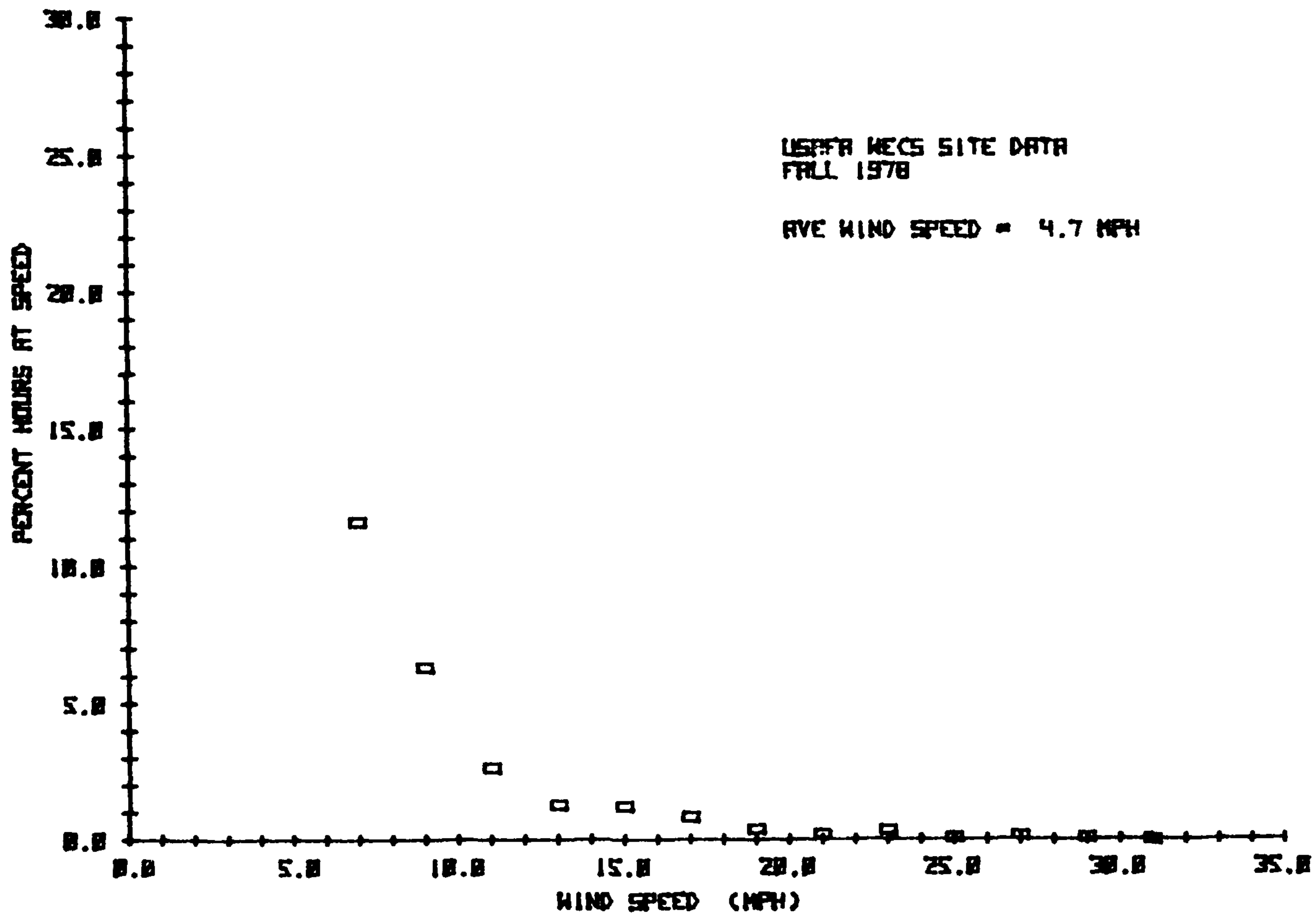



Figure A-7. Percent Hours at Speed, USAFA WECS Site, Fall 1978

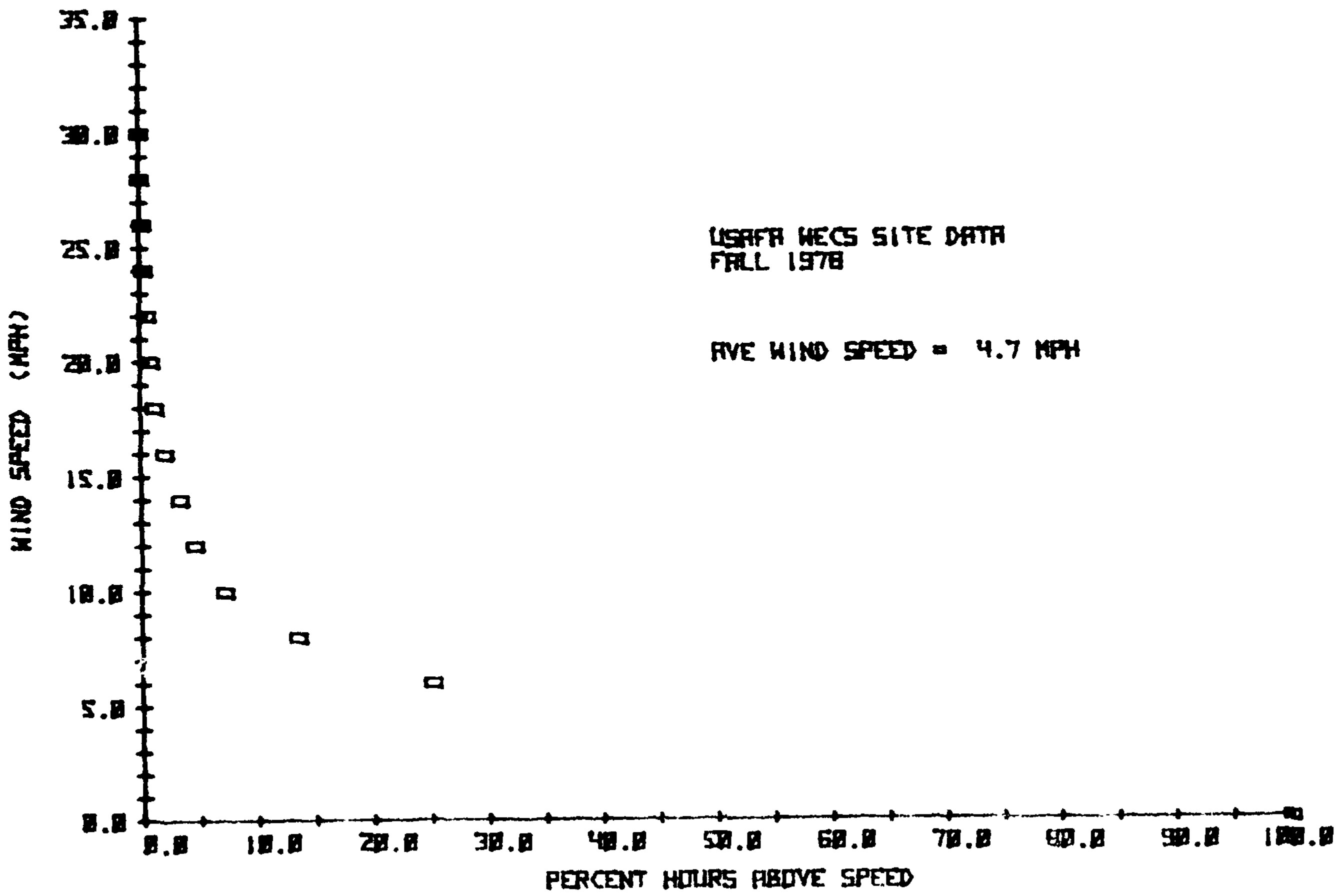



Figure A-8. Percent Hours Above Speed, USAFA WECS Site, Fall 1978

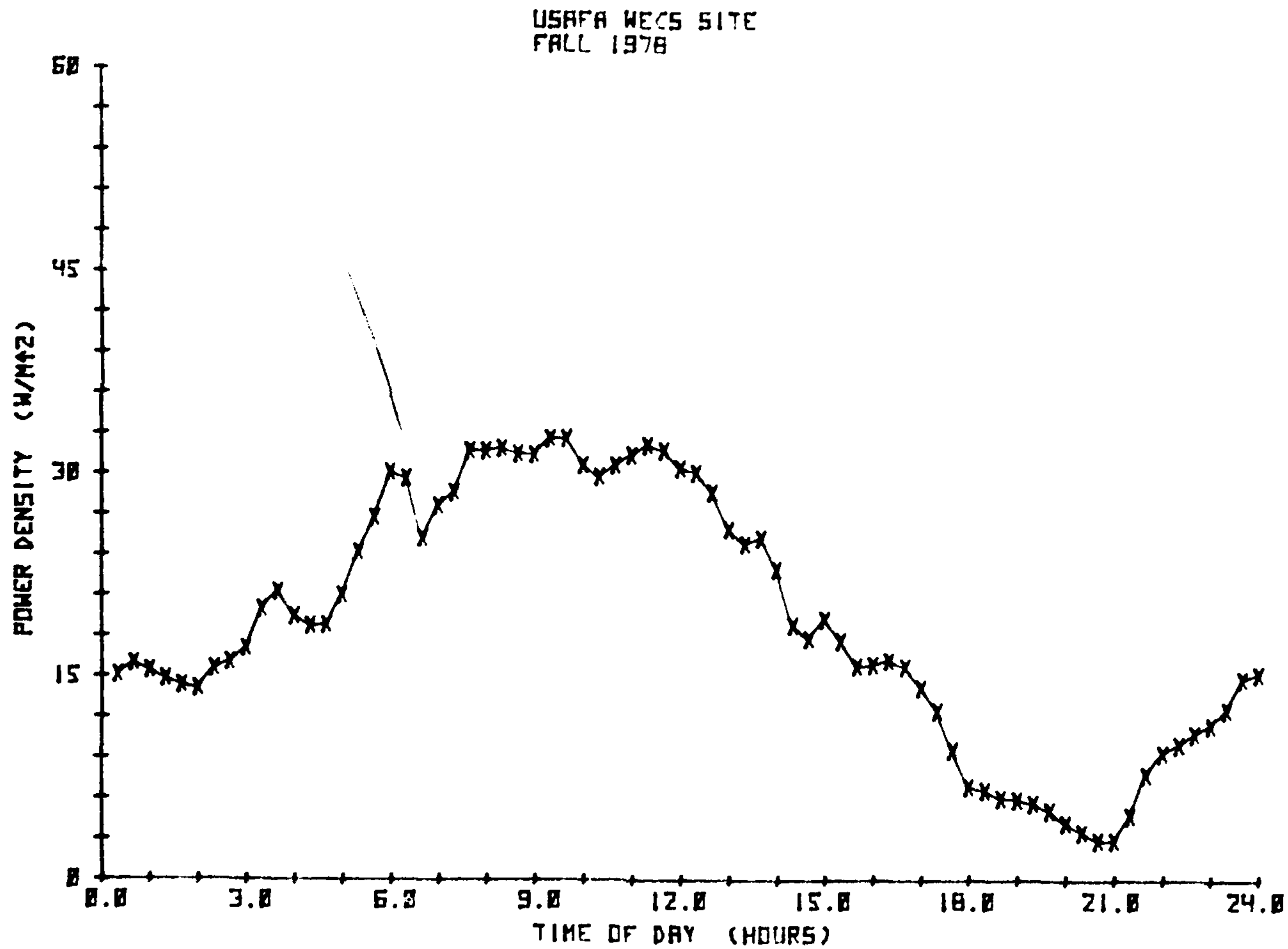



Figure A-9. Power Density,
USAFA WECS Site, Fall 1978

TABLE A-4: WIND SPEED OCCURRENCE VS. DIRECTION, USAFA WECS SITE, WINTER 1978

THE F[illegible]
WINTER 1978 [illegible] SITE

| DIRECTION | 5 | 8 | 11 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | [illegible] | 28 | [illegible] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 51 | 8 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | 0 | 0 |
| 20 | 58 | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 40 | 54 | 8 | [illegible] | 0 | 0 | [illegible] | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 60 | 35 | 4 | [illegible] | 0 | 0 | [illegible] | 0 | 0 | 0 | [illegible] | | | 0 | [illegible] |
| 80 | 35 | 4 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | [illegible] | 0 | 0 |
| 100 | 67 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 120 | 227 | 33 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 140 | 112 | 16 | [illegible] | 1 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 160 | 73 | 3 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 180 | 106 | 11 | [illegible] | 0 | [illegible] | 0 | 0 | 0 | [illegible] | 0 | [illegible] | [illegible] | 0 | 0 |
| 200 | 83 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 220 | 61 | 3 | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 240 | 50 | 3 | 4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | 0 | | [illegible] | 0 | 0 |
| 260 | 43 | 9 | 14 | 4 | | [illegible] | [illegible] | [illegible] | 0 | 0 | [illegible] | [illegible] | 0 | 0 |
| 280 | 50 | 7 | 2 | 5 | 1 | 5 | [illegible] | 1 | 1 | 0 | | [illegible] | 0 | 0 |
| 300 | 72 | 7 | [illegible] | 9 | 11 | 10 | 8 | 9 | [illegible] | 12 | [illegible] | [illegible] | 0 | 0 |
| 320 | 101 | 11 | [illegible] | 13 | 17 | [illegible] | 8 | 4 | 5 | 1 | | | 0 | 0 |
| 340 | 71 | 14 | 11 | [illegible] | [illegible] | 1 | 0 | 0 | 0 | [illegible] | [illegible] | | 0 | 0 |

TOTAL 1 [illegible] 154 [illegible]

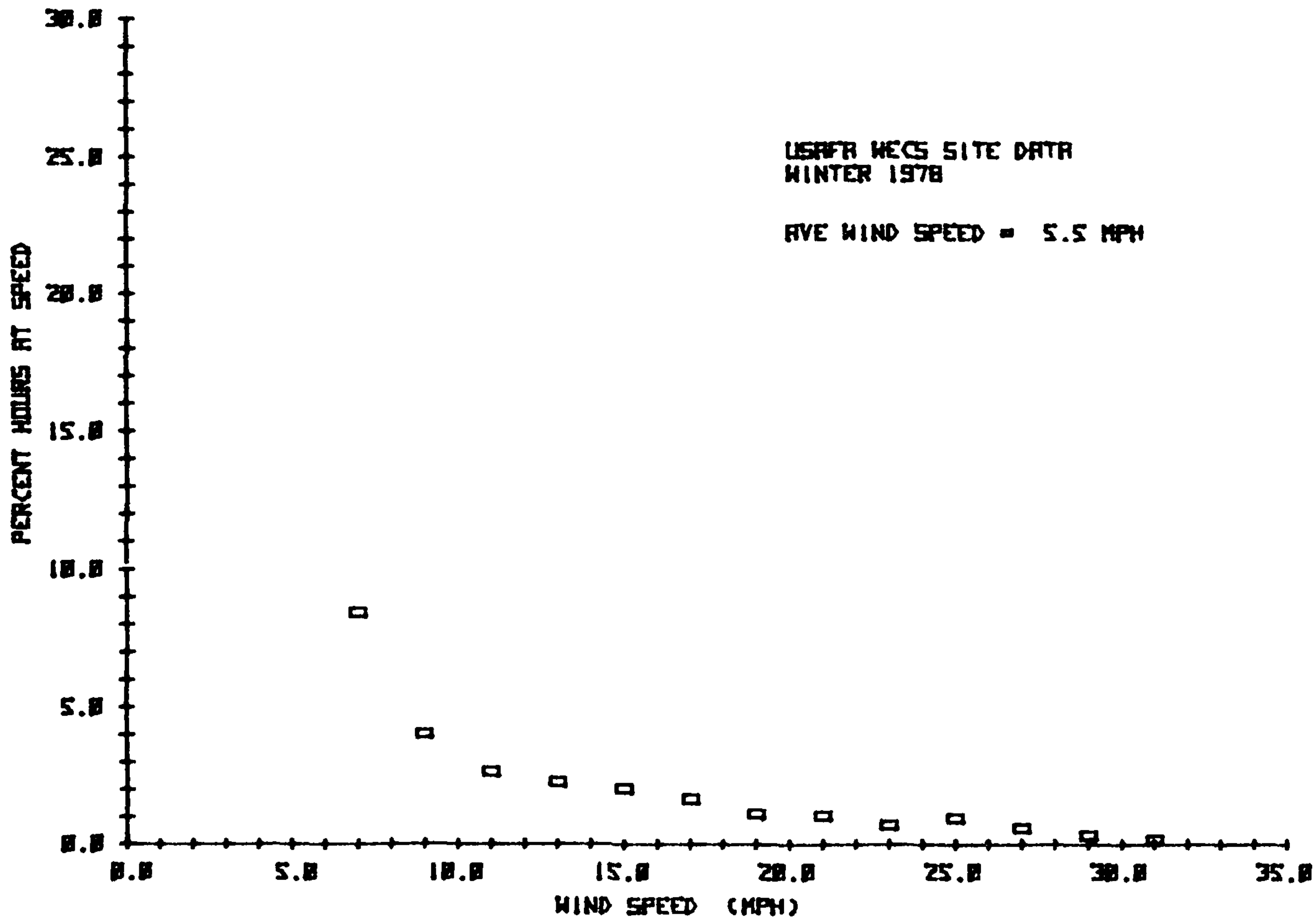



Figure A-10. Percent Hours at Speed,
USAFA WECS Site, Winter 1978

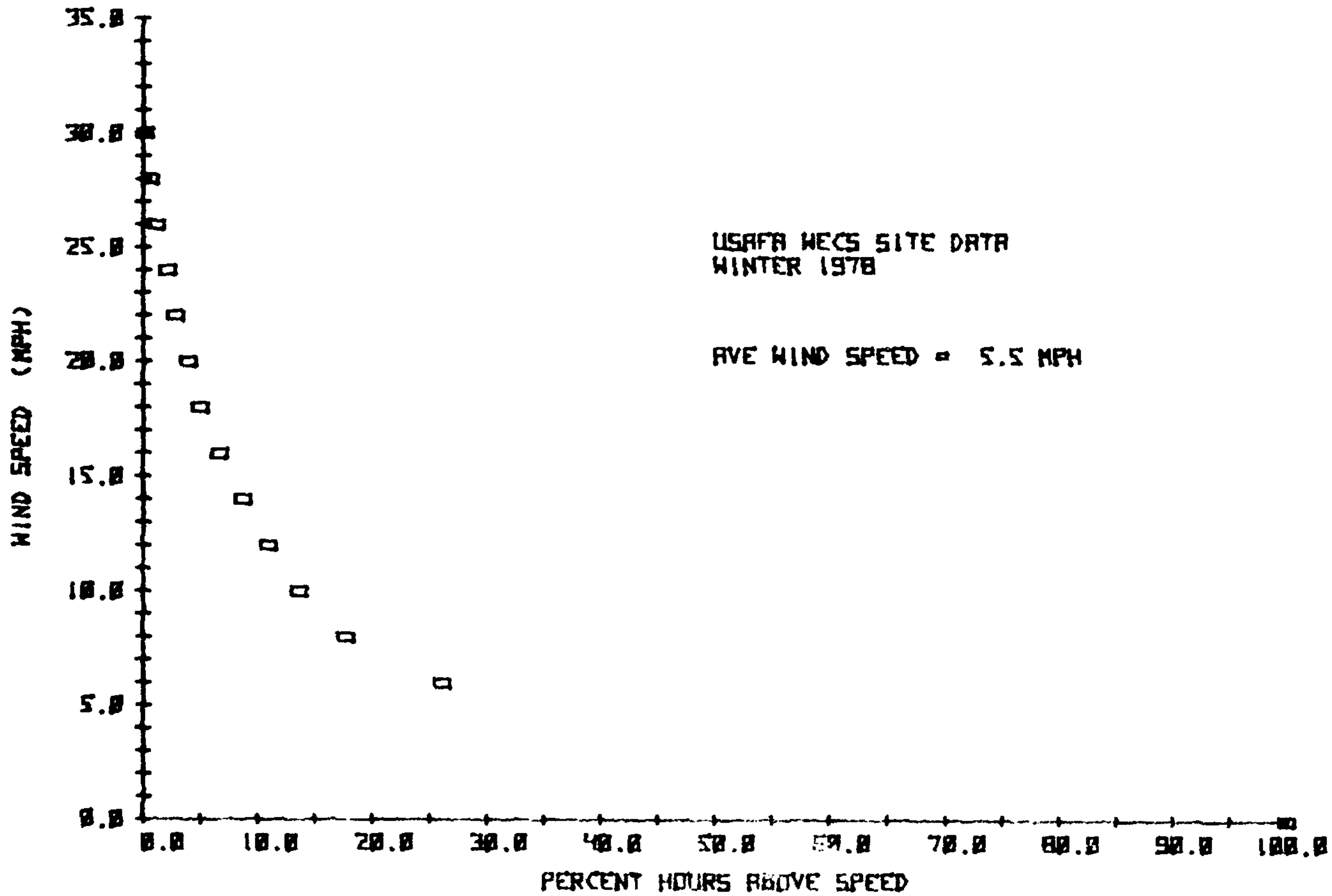
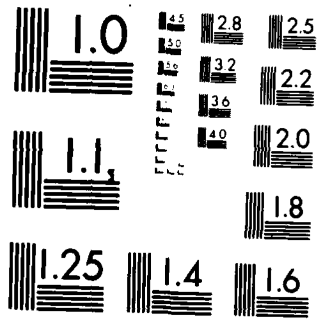



Figure A-11. Percent Hours Above Speed,
USAFA WECS Site, Winter 1978

AD-A129 581 USAF (UNITED STATES AIR FORCE) ACADEMY WIND SITE SURVEY: METHODOLOGIES FO..(U) AIR FORCE ENGINEERING AND SERVICES CENTER TYDALL AFB FL ENGIN.. 2/2

UNCLASSIFIED T E KULLGREN ET AL. MAR 83 F/G 4/2 NL

END
DATE
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

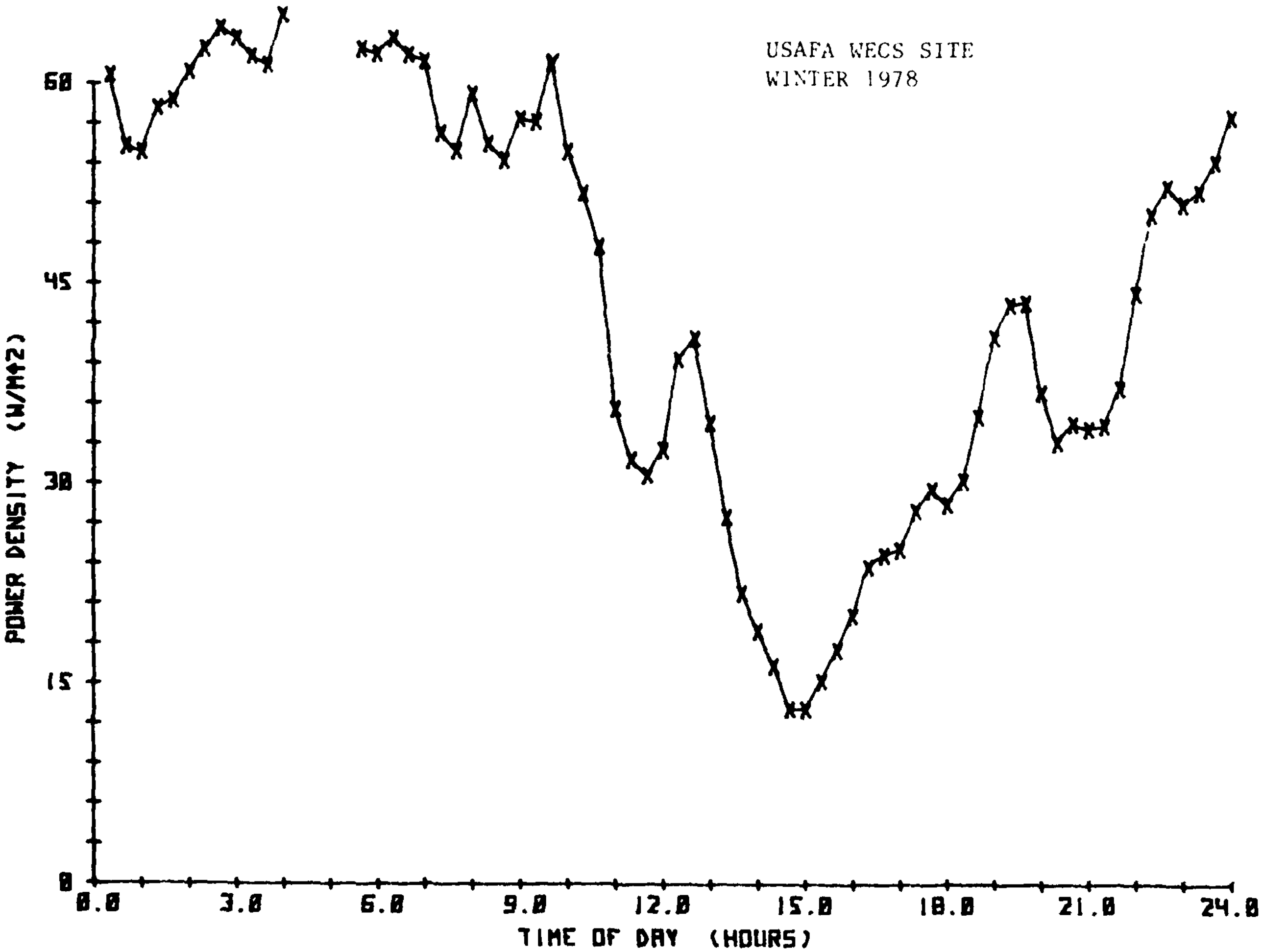



Figure A-12. Power Density, USAFA WECS Site, Winter 1978

TABLE A-5: WIND SPEED OCCURRENCE VS. DIRECTION, USAFA WECS SITE, CALENDAR YEAR 1978

THE FOLLOWING TIMES ARE DATA COLLECTED:
CY 1978 USAFA WECS SITE

| DIRECTION | VELOCITY <6 | <8 | <10 | <12 | <14 | <16 | <18 | <20 | <22 | <24 | <26 | <28 | <30 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 169 | 17 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 121 | 11 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 109 | 11 | 7 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 127 | 17 | 8 | 5 | 2 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 80 | 160 | 16 | 8 | 5 | 2 | 1 | 1 | 0 | 0 | 3 | 2 | 2 | 1 | 0 |
| 100 | 291 | 39 | 14 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120 | 727 | 231 | 128 | 52 | 18 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 140 | 668 | 142 | 59 | 14 | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 160 | 399 | 23 | 11 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180 | 249 | 16 | 7 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200 | 201 | 26 | 11 | 5 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 220 | 204 | 30 | 21 | 16 | 10 | 8 | 4 | 3 | 0 | 1 | 0 | 0 | 0 | 0 |
| 240 | 208 | 40 | 57 | 52 | 56 | 57 | 52 | 38 | 24 | 19 | 11 | 12 | 3 | 4 |
| 260 | 229 | 64 | 59 | 39 | 28 | 17 | 13 | 8 | 7 | 4 | 4 | 1 | 2 | 2 |
| 280 | 252 | 34 | 22 | 10 | 4 | 2 | 3 | 2 | 0 | 1 | 0 | 0 | 0 | 0 |
| 300 | 341 | 21 | 7 | 3 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 320 | 514 | 30 | 9 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 340 | 362 | 38 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTALS | 5332 | 907 | 423 | 211 | 131 | [illegible] | 76 | [illegible] | 22 | 27 | [illegible] | 14 | 6 | 6 |

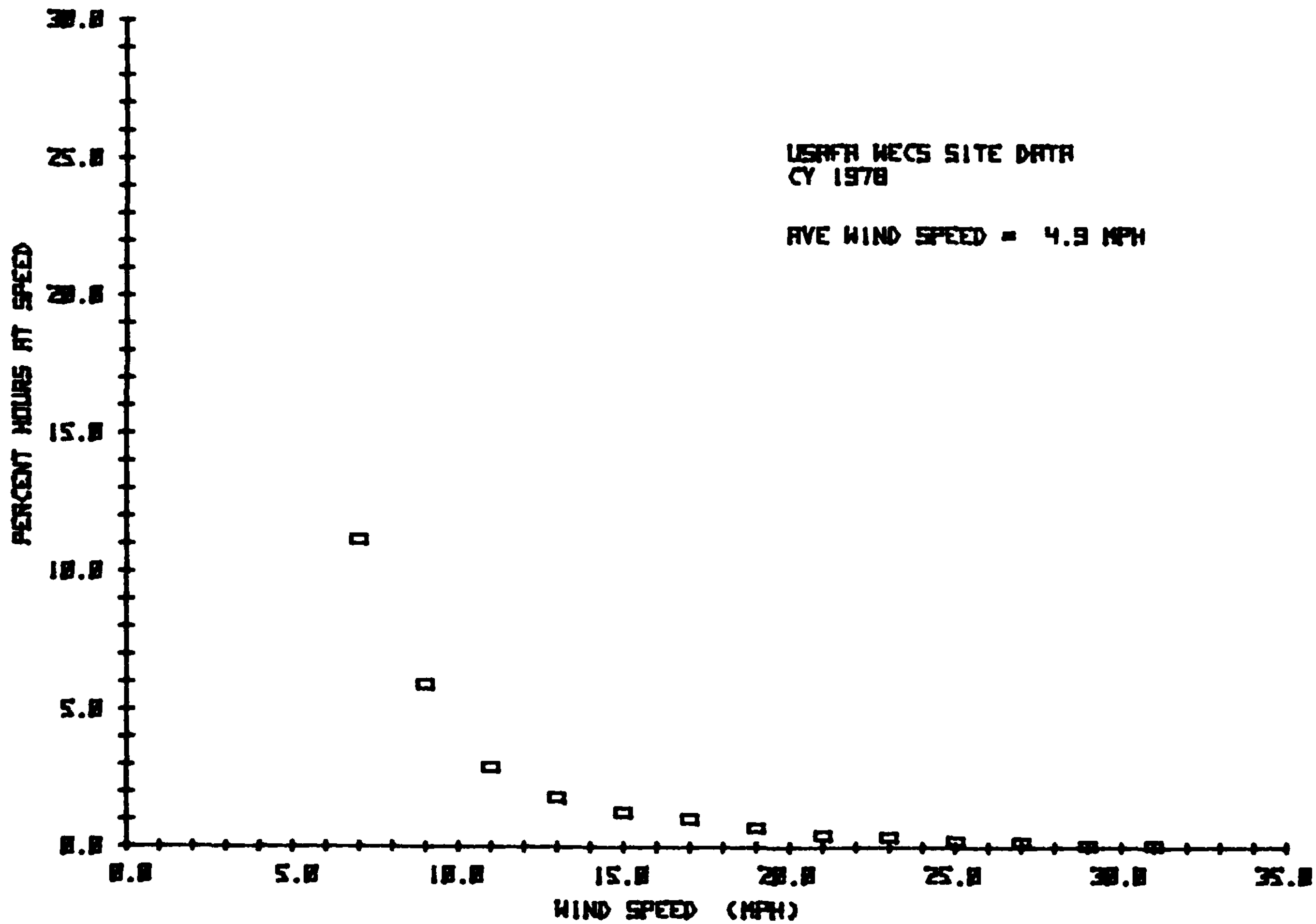



Figure A-13. Percent Hours at Speed,
USAFA WECS Site, Calendar Year 1978

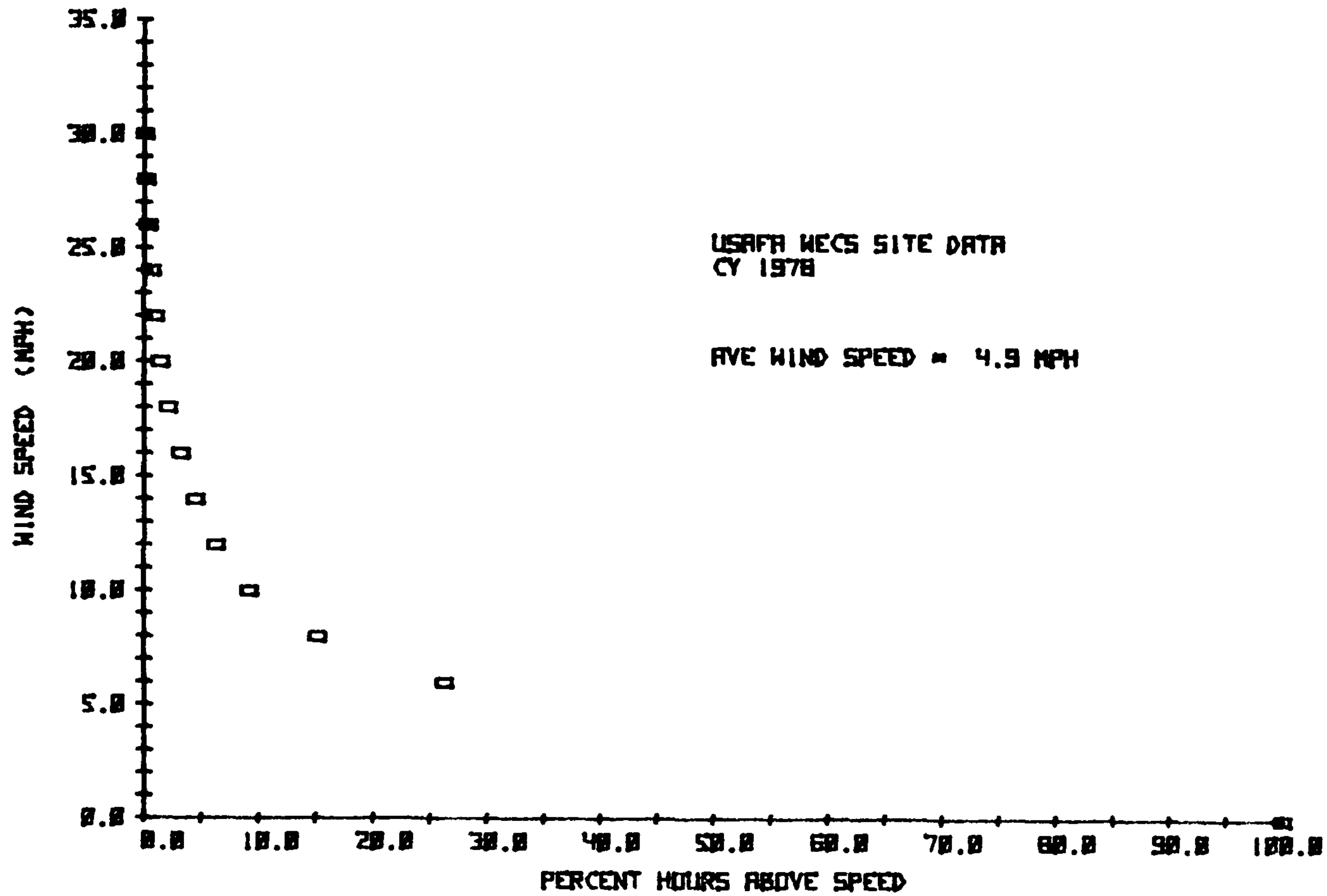



Figure A-14. Percent Hours Above Speed,
USAFA WECS Site, Calendar Year 1978

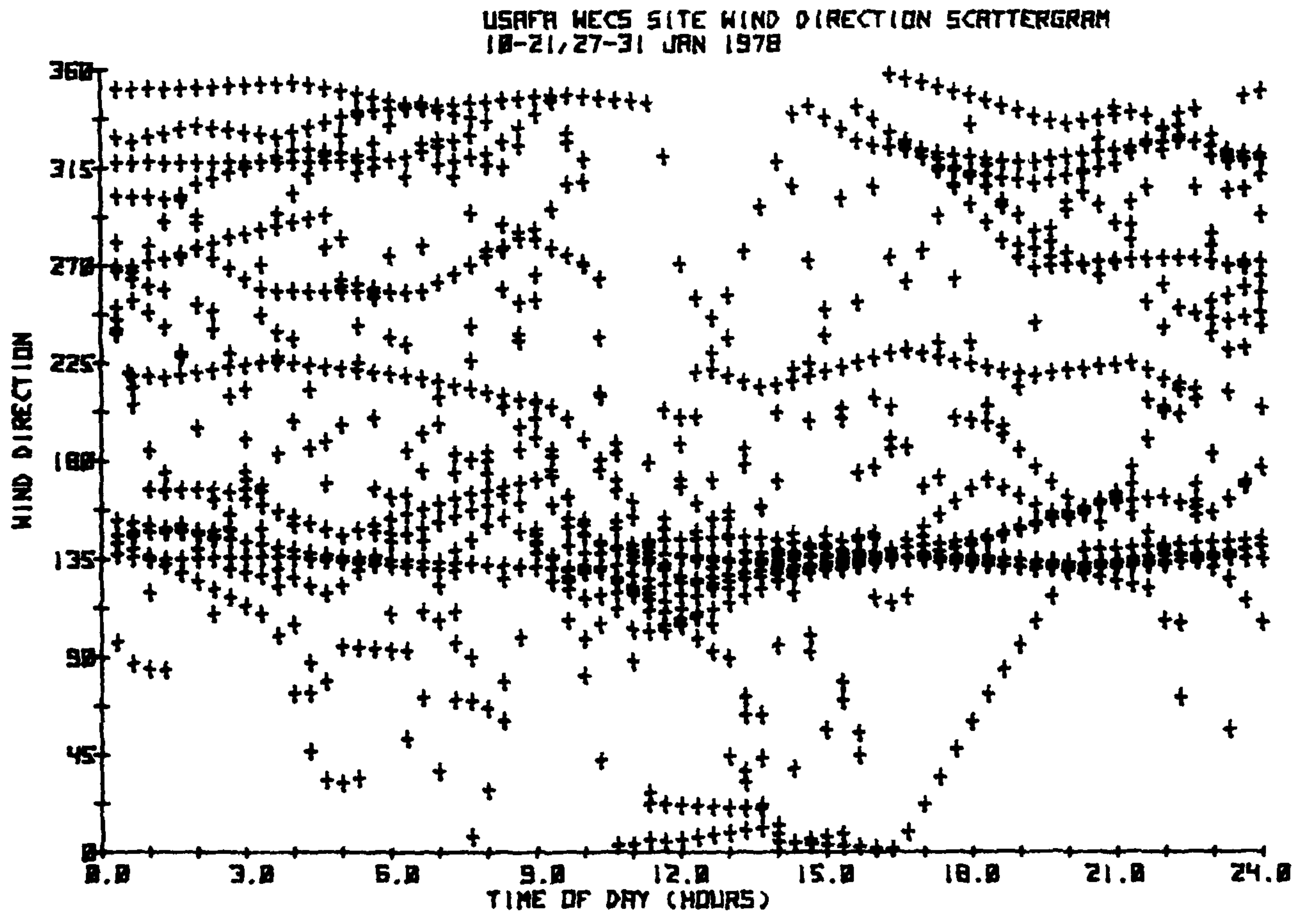



Figure A-15. Wind Direction vs. Time of Day,
USAFA WECS Site, Jan 1978

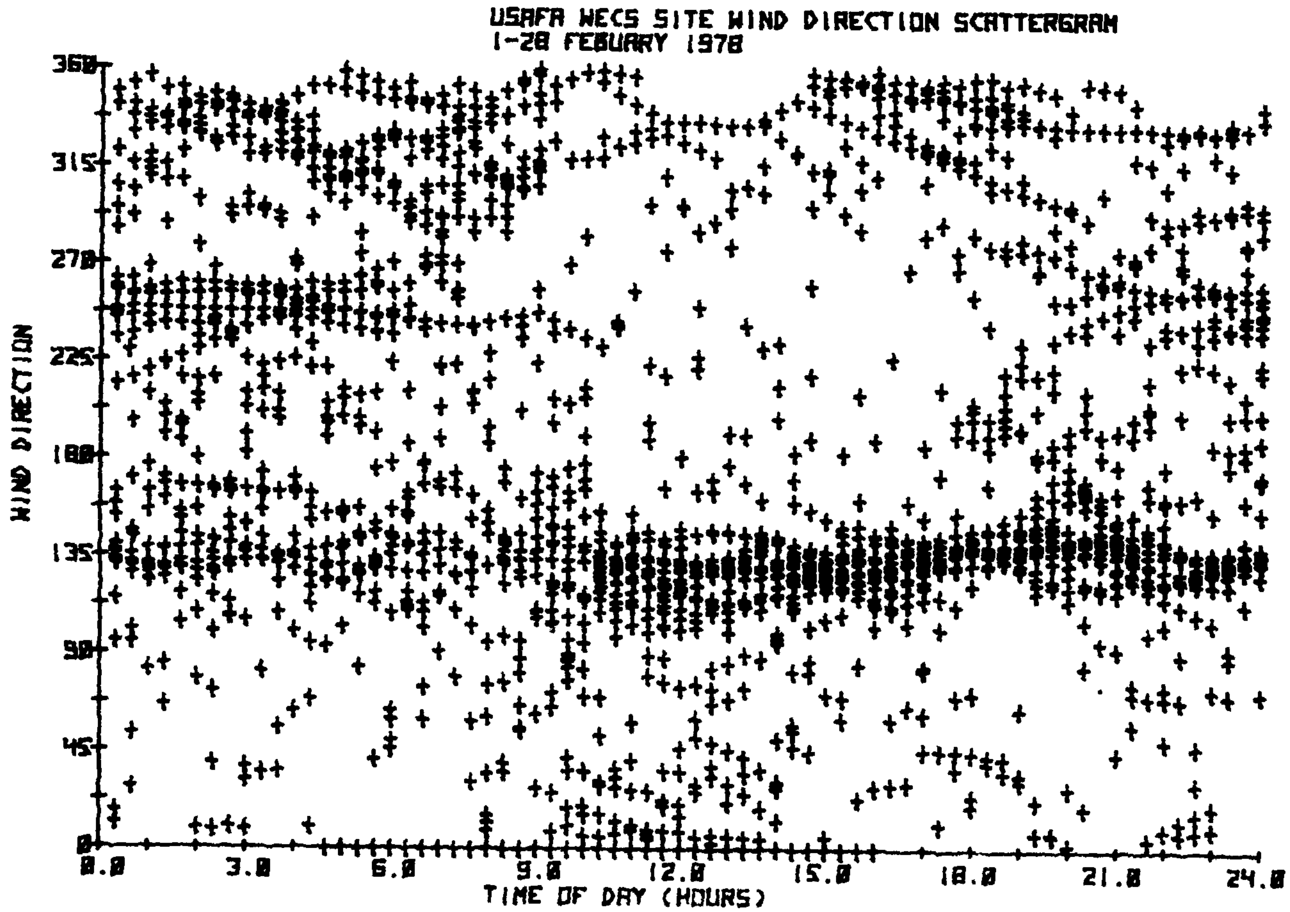



Figure A-16. Wind Direction vs. Time of Day, USAFA WECS Site, Feb 1978

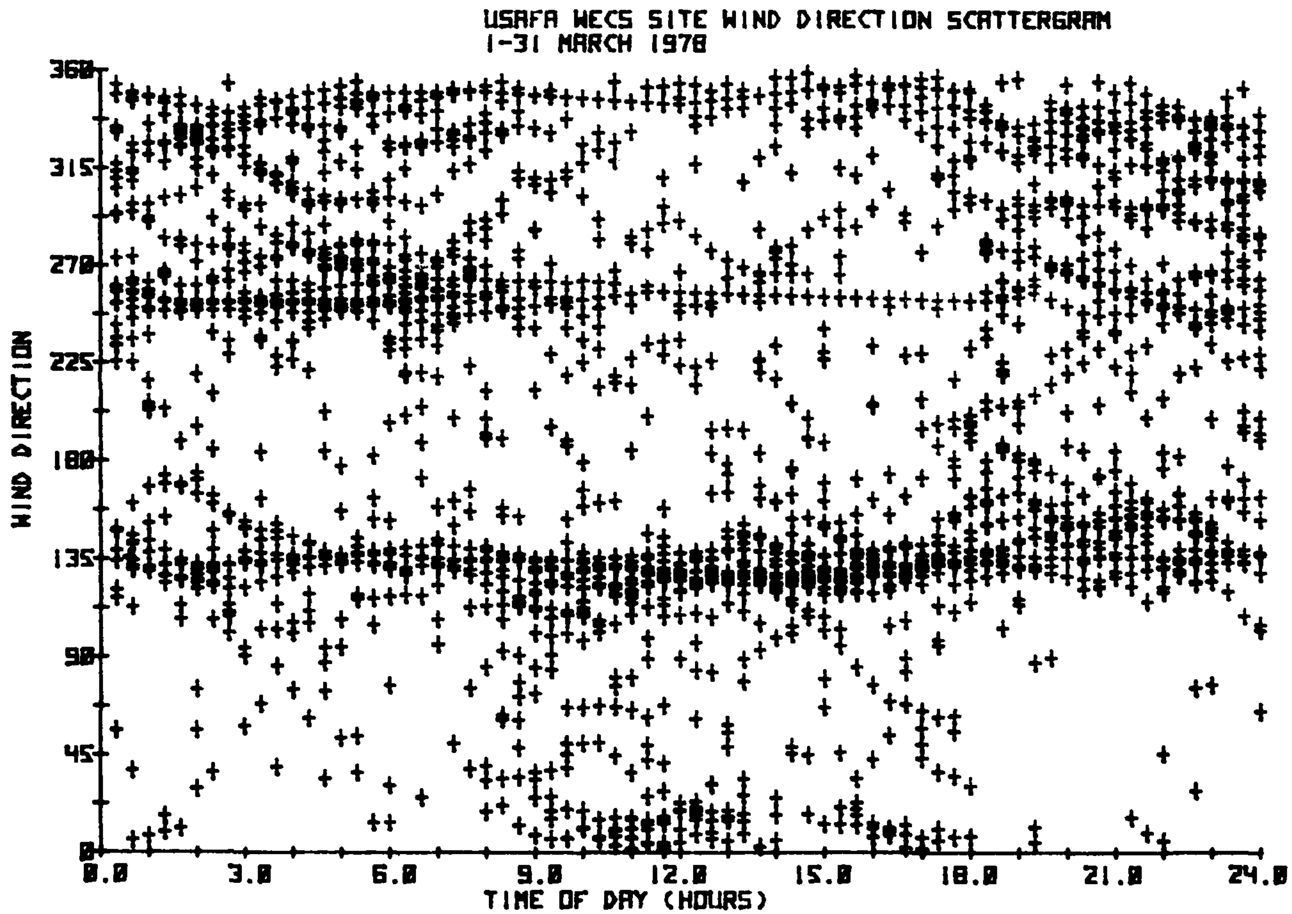



Figure A-17. Wind Direction vs. Time of Day,
USAFA WECS Site, Mar 1978

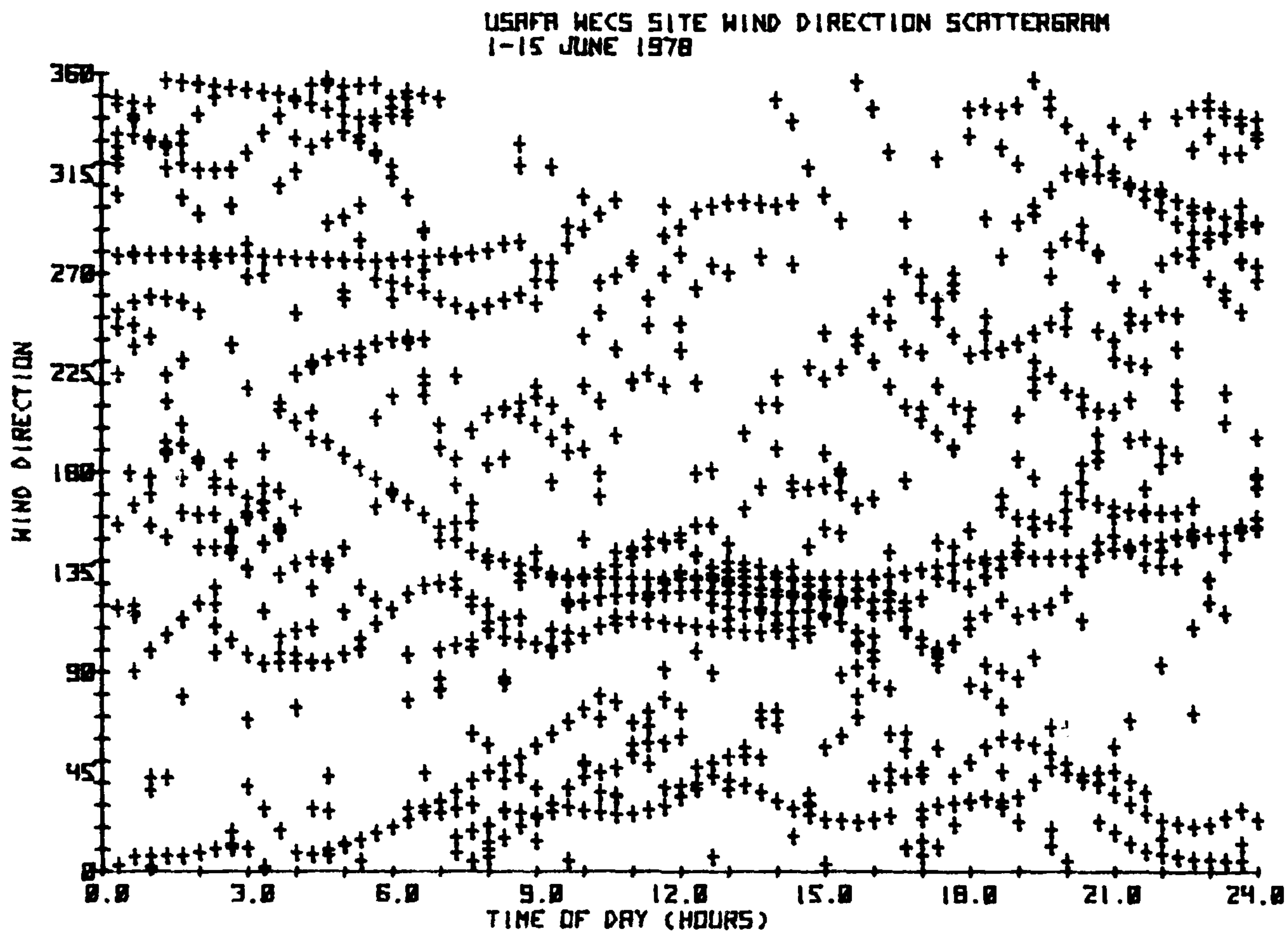



Figure A-18. Wind Direction vs. Time of Day, USAFA WECS Site, Jun 1978

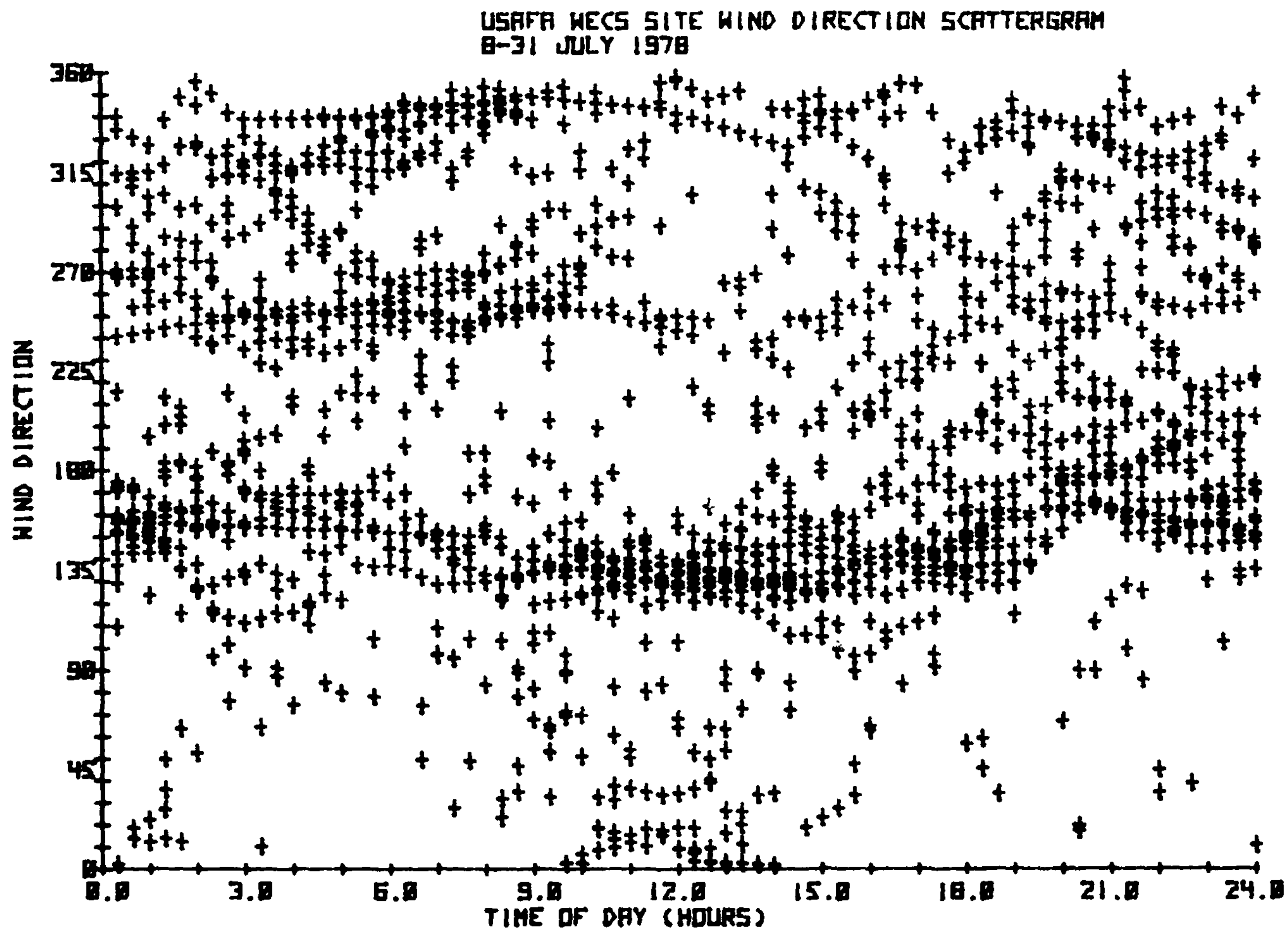



Figure A-19. Wind Direction vs. Time of Day, USAFA WECS Site, Jul 1978

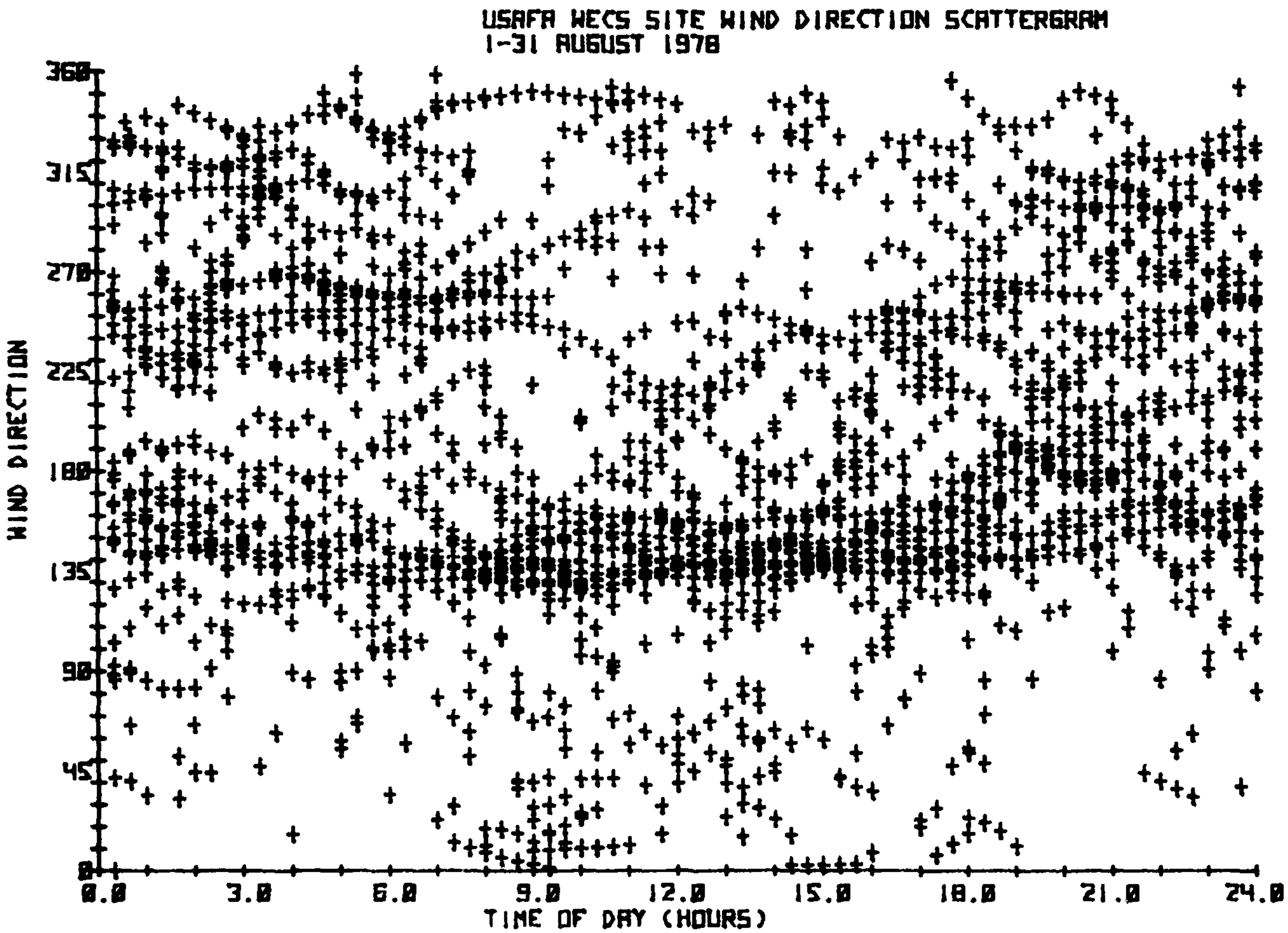



Figure A-20. Wind Direction vs. Time of Day, USAFA WECS Site, Aug 1978

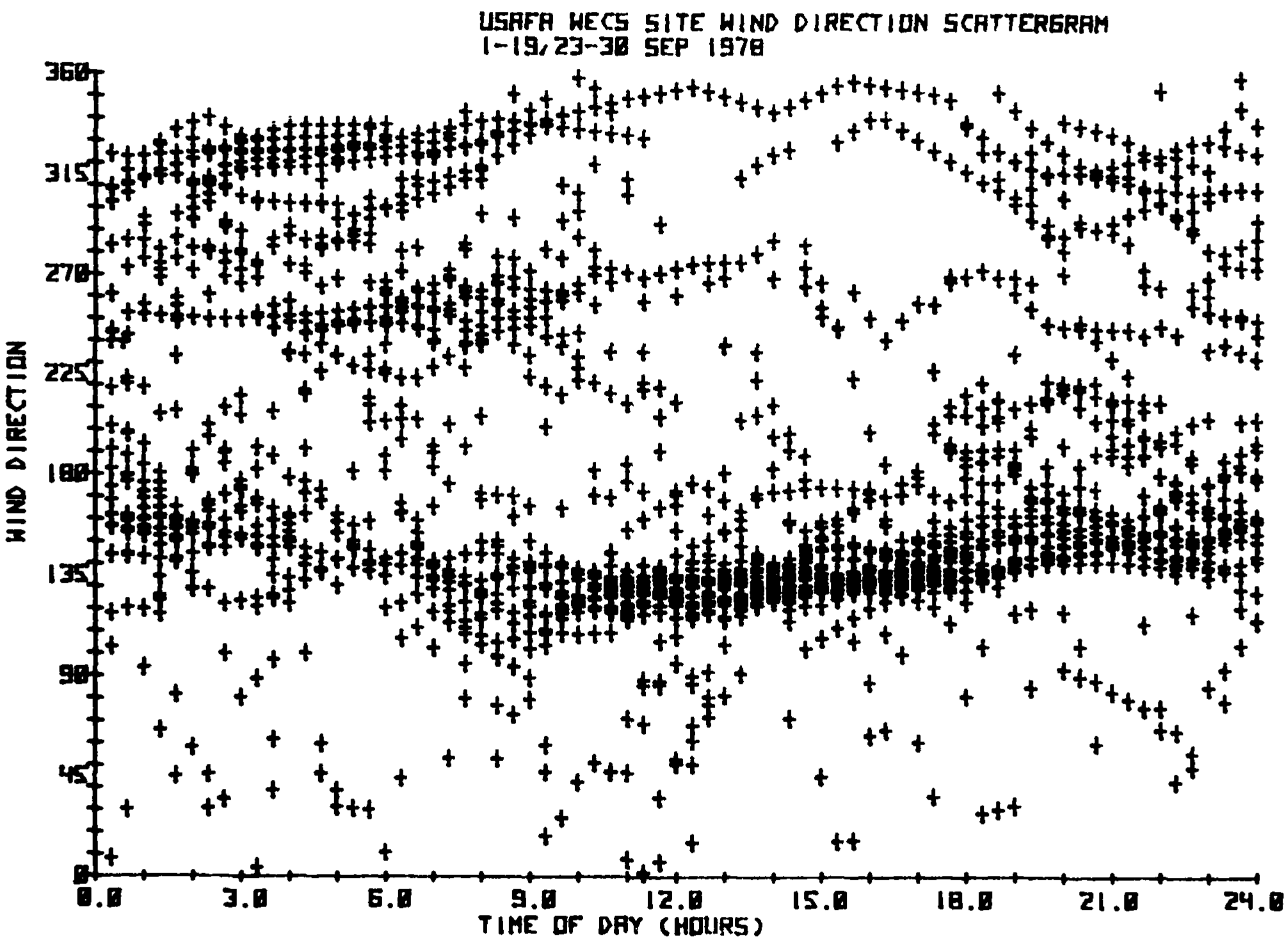



Figure A-21. Wind Direction vs. Time of Day, USAFA WECS Site, Sep 1978

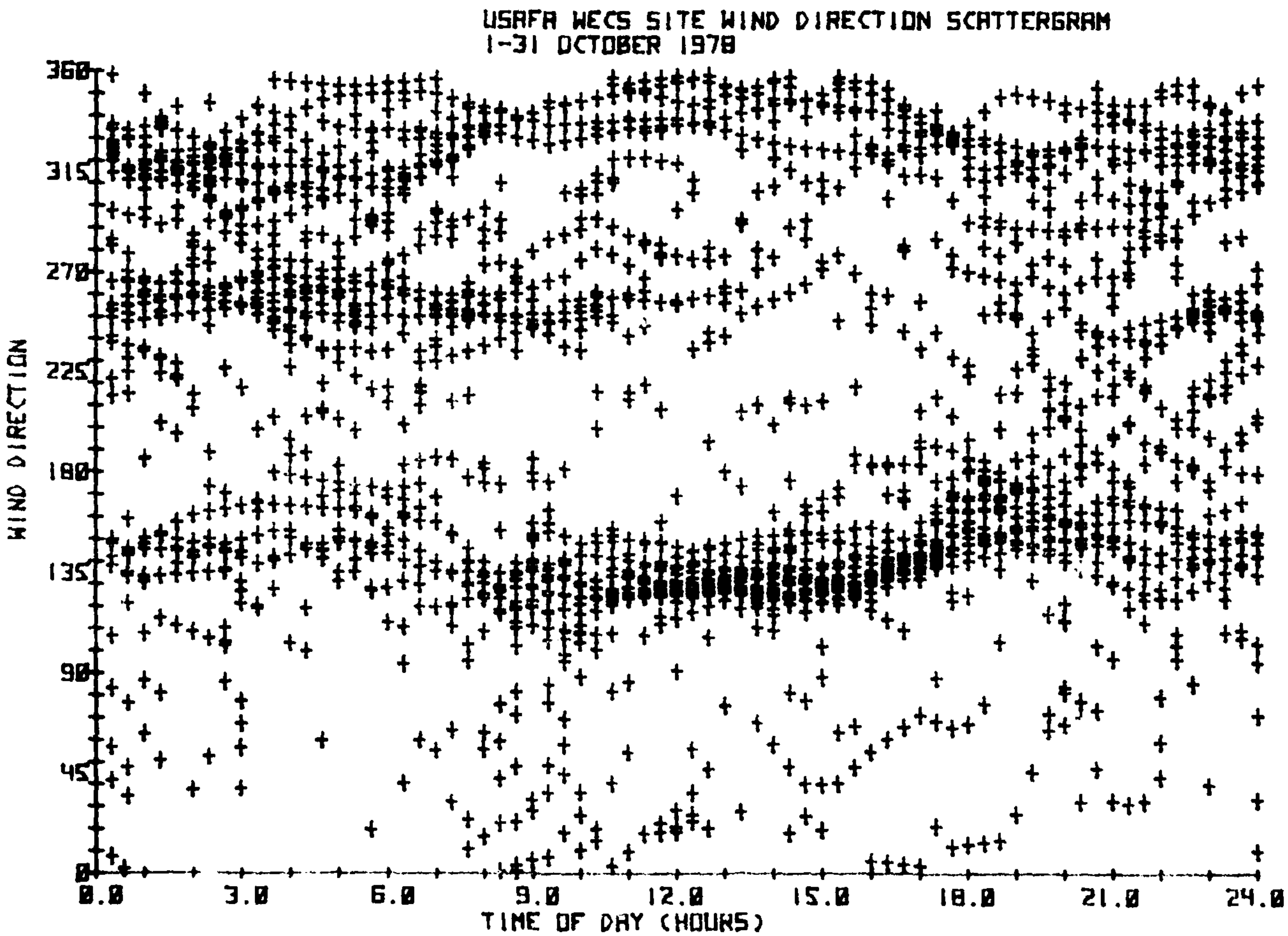



Figure A-22. Wind Direction vs. Time of Day, USAFA WECS Site, Oct 1978

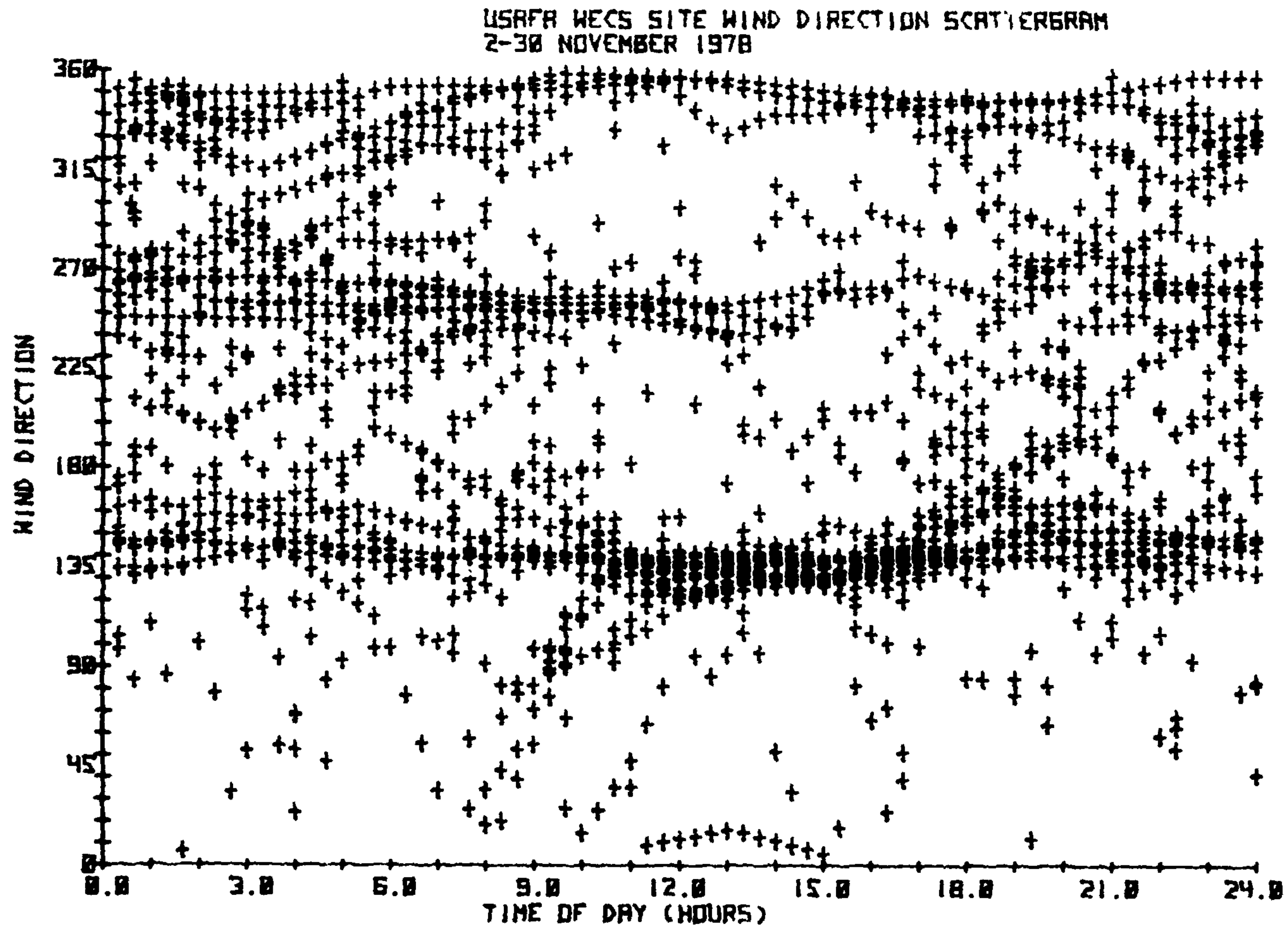



Figure A-23. Wind Direction vs. Time of Day, USAFA WECS Site, Nov 1978

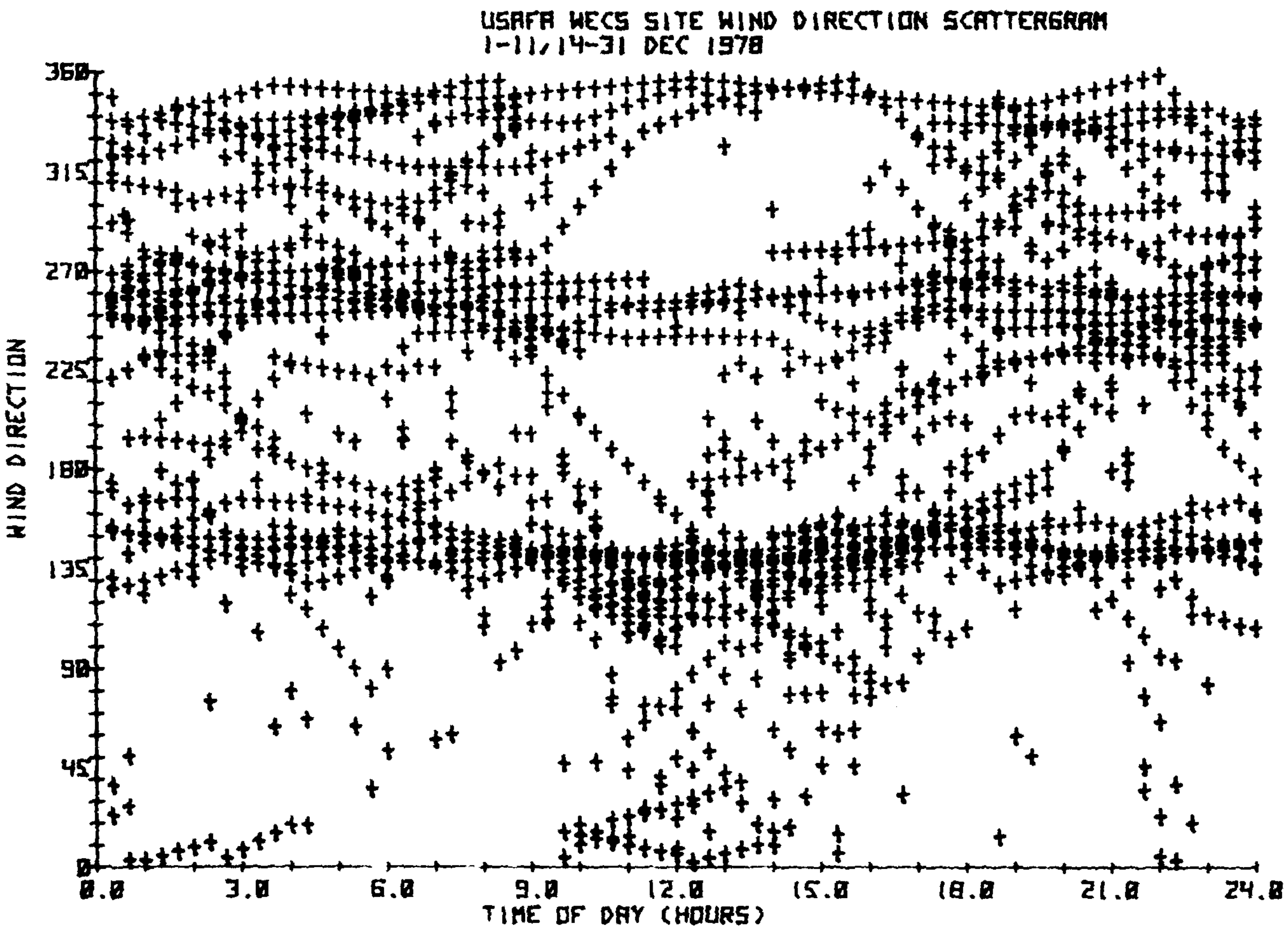



Figure A-24. Wind Direction vs. Time of Day, USAFA WECS Site, Dec 1978

TABLE A-6: WIND SPEED OCCURRENCE VS. DIRECTION, SITE #1, SUMMER 1979

USAFA COMPILATOR SITE, SUMMER 1979

| WIND SPEED | SE | E | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0- 2 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| 2- 4 | 307845 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| 4- 6 | 528432 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| 6- 8 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| 8- 10 | 472564 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| 10- 12 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| 12- 14 | 340795 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| 14- 16 | 254401 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 254401 |
| 16- 18 | 131390 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 131390 |
| 18- 20 | 89755 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 89755 |
| 20- 22 | 182655 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 182655 |
| 22- 24 | 98098 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 98098 |
| 24- 26 | 103994 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 103994 |
| 26- 28 | 64626 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 64626 |
| 28- 30 | 39524 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39524 |
| 30- 32 | 37214 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37214 |
| 32- 34 | 5560 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| 34- 36 | 3038 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3038 |
| 36- 38 | 3136 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3136 |
| 38- 40 | 1479 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1479 |
| 40- 42 | 1167 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1167 |
| 42- 44 | 511 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 511 |
| 44- 46 | 255 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 255 |
| 46- 48 | 158 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 158 |
| 48- 50 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| 50- 52 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 48 |
| 52- 54 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 |
| 54- 56 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 56- 58 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 58- 60 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 60- 62 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 62- 64 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

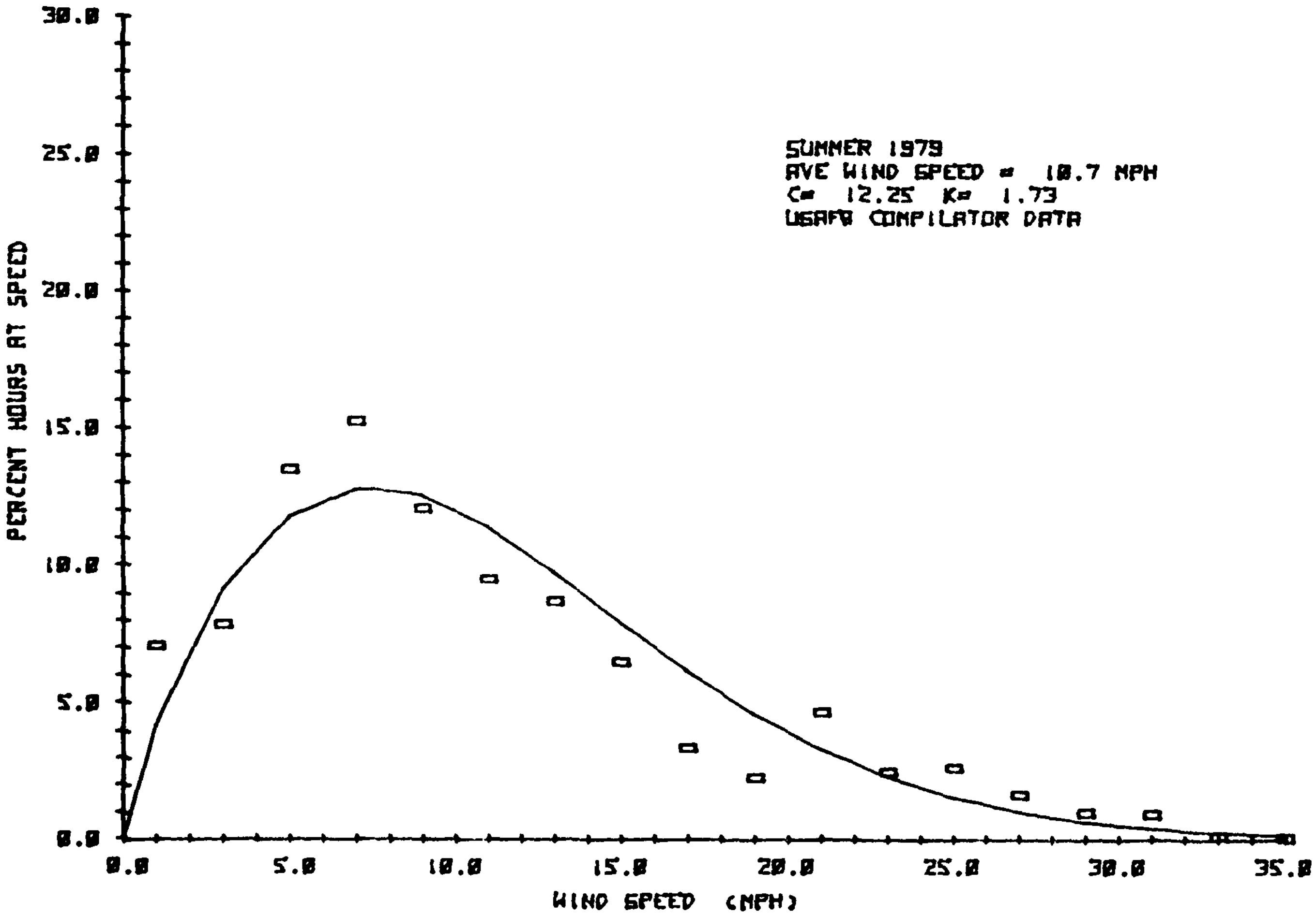



Figure A-25. Percent Time at Speed, Site #1, Summer 1979

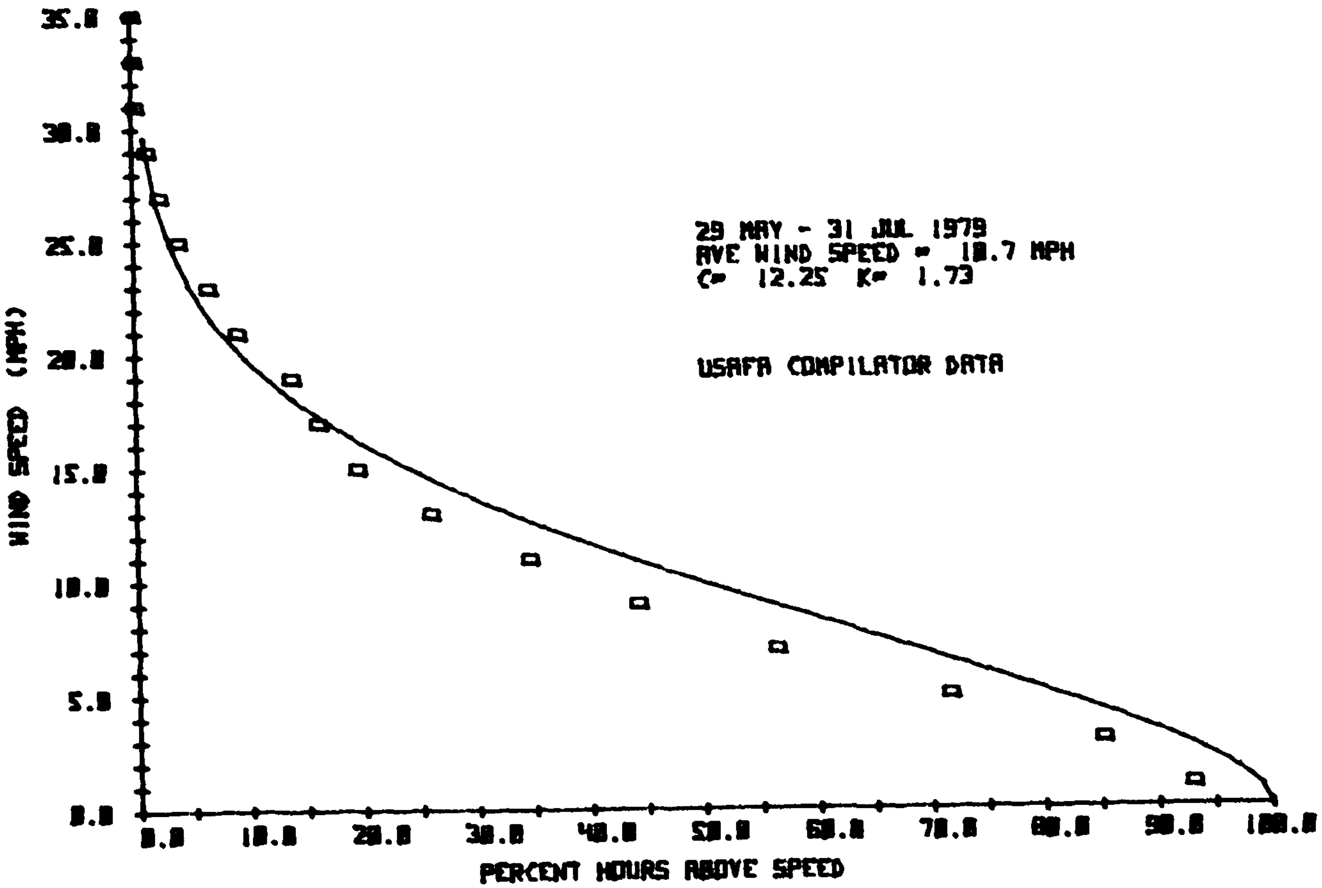



Figure A-26. Percent Time Above Speed, Site #1, Summer 1979

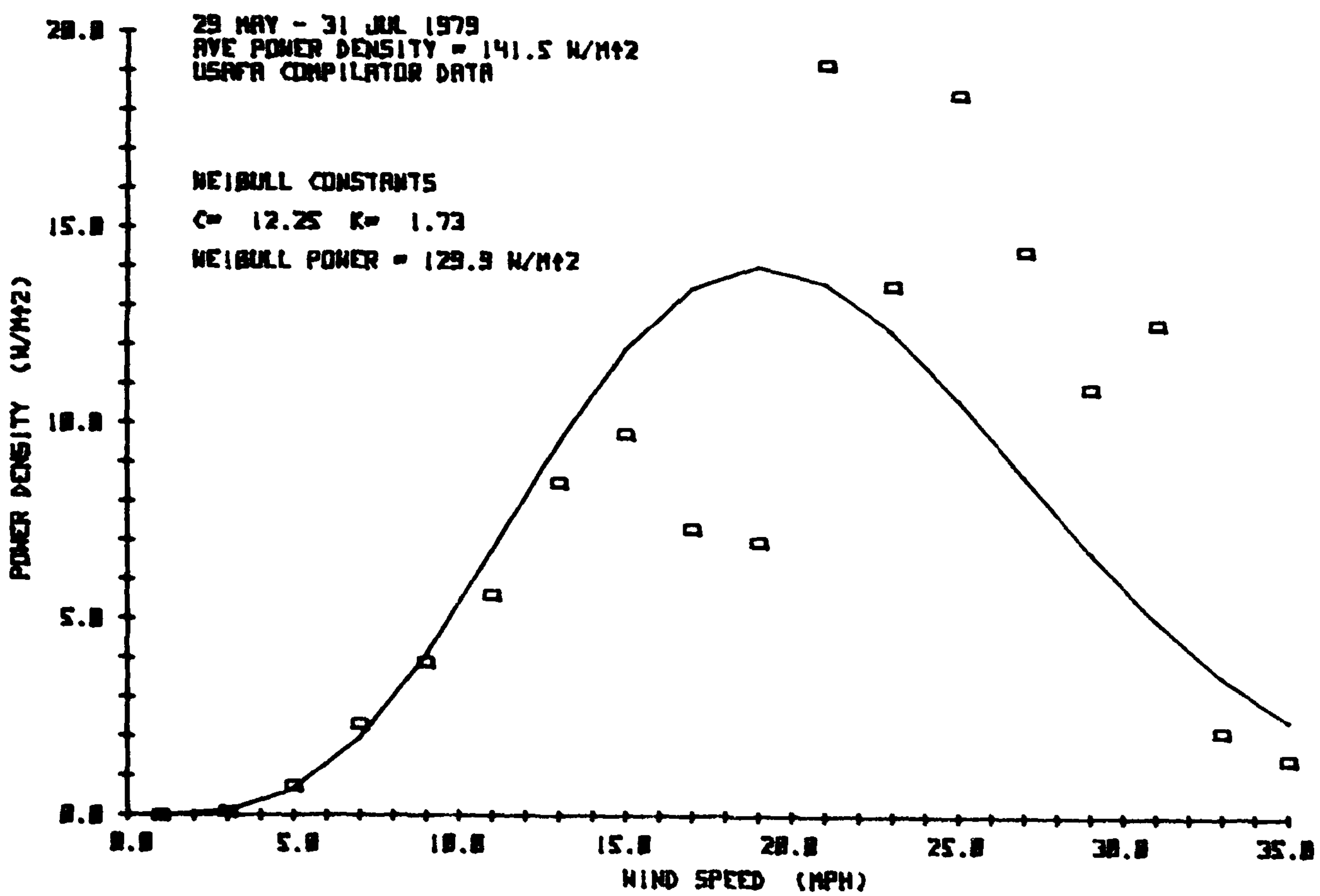



Figure A-27. Power Density,
Site #1, Summer 1979

TABLE A-7: WIND SPEED OCCURRENCE VS. DIRECTION, SITE #1, FALL 197[illegible]

| WIND SPEED (MPH) | SE | E | NE | N | NW | W | SW | [illegible] | TOTAL TIME [illegible] |
|---|---|---|---|---|---|---|---|---|---|
| 0- 2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2- 4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 4- 6 | 24971 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 6- 8 | 13406 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8- 10 | 6141 | 13256 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 10- 12 | 3076 | 9842 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 12- 14 | 1304 | 5521 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 351628 |
| 14- 16 | 424 | 2725 | [illegible] | 19907 | [illegible] | [illegible] | [illegible] | [illegible] | 267490 |
| 16- 18 | 106 | 1362 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 194081 |
| 18- 20 | 29 | 897 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 140599 |
| 20- 22 | 11 | 574 | [illegible] | [illegible] | 15617 | [illegible] | [illegible] | [illegible] | [illegible] |
| 22- 24 | 11 | 384 | 43034 | 4950 | 9209 | [illegible] | [illegible] | 1305 | 70596 |
| 24- 26 | 5 | 223 | 31965 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26- 28 | 0 | 90 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28- 30 | 0 | 76 | 18450 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30- 32 | 0 | 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32- 34 | 0 | 30 | [illegible] | 1651 | [illegible] | [illegible] | [illegible] | 4 | [illegible] |
| 34- 36 | 0 | 22 | [illegible] | [illegible] | 631 | 524 | [illegible] | 0 | [illegible] |
| 36- 38 | 0 | 12 | [illegible] | [illegible] | [illegible] | [illegible] | 190 | 0 | [illegible] |
| 38- 40 | 0 | 14 | [illegible] | 1419 | [illegible] | 308 | [illegible] | [illegible] | [illegible] |
| 40- 42 | 0 | 9 | [illegible] | 1166 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 42- 44 | 0 | 6 | [illegible] | 914 | [illegible] | [illegible] | [illegible] | [illegible] | 11561 |
| 44- 46 | 0 | 6 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0 | [illegible] |
| 46- 48 | 0 | 5 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0 | [illegible] |
| 48- 50 | 0 | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0 | [illegible] |
| 50- 52 | 0 | 1 | 1614 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 1855 |
| 52- 54 | 0 | 0 | [illegible] | [illegible] | [illegible] | 15 | [illegible] | 0 | 886 |
| 54- 56 | 0 | 1 | [illegible] | 45 | [illegible] | [illegible] | [illegible] | 0 | 446 |
| 56- 58 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | [illegible] |
| 58- 60 | 0 | 0 | [illegible] | [illegible] | [illegible] | 5 | 0 | 0 | [illegible] |
| 60- 62 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 44 |
| [illegible] | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | [illegible] |

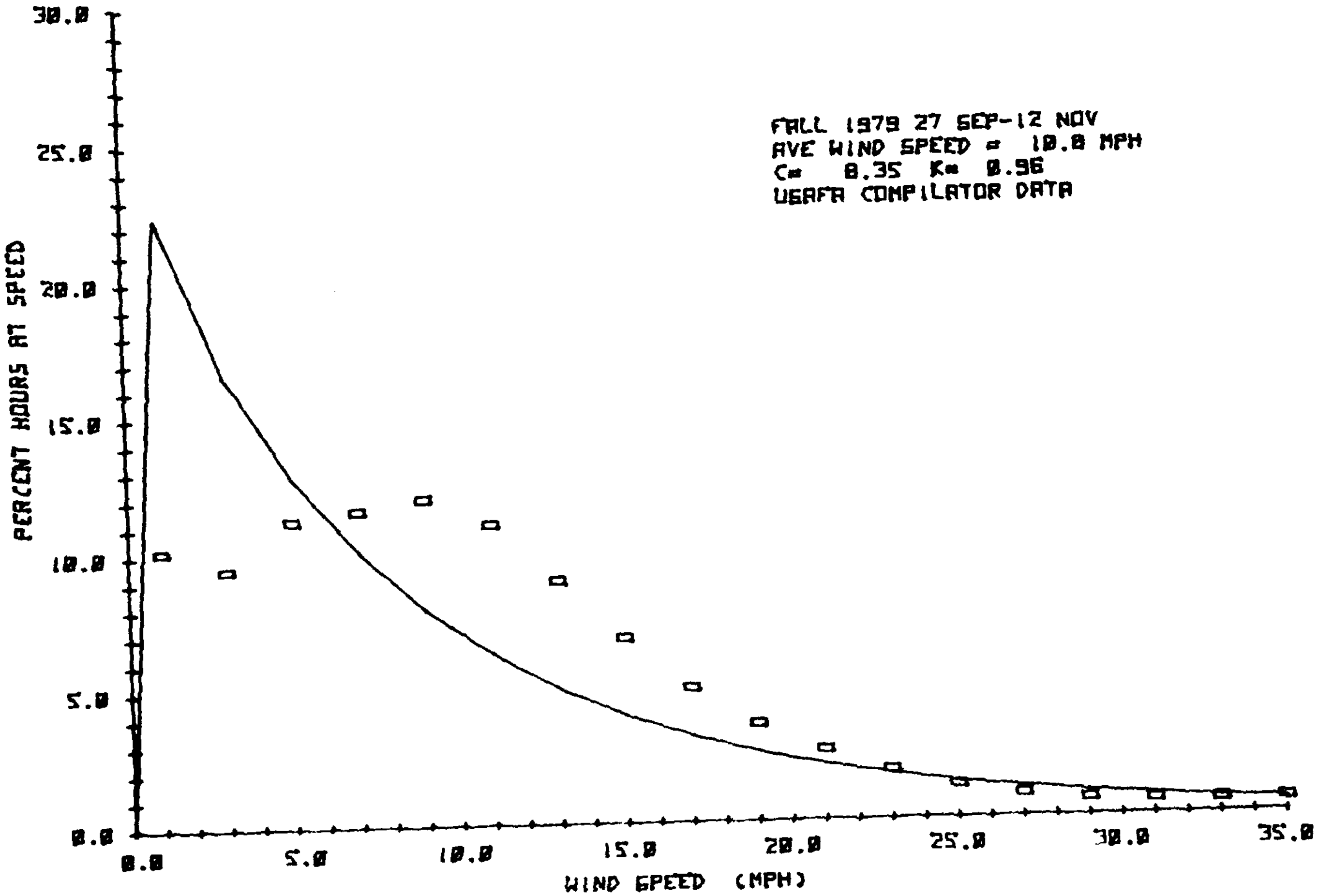



Figure A-28. Percent Time at Speed,
Site #1, Fall 1979

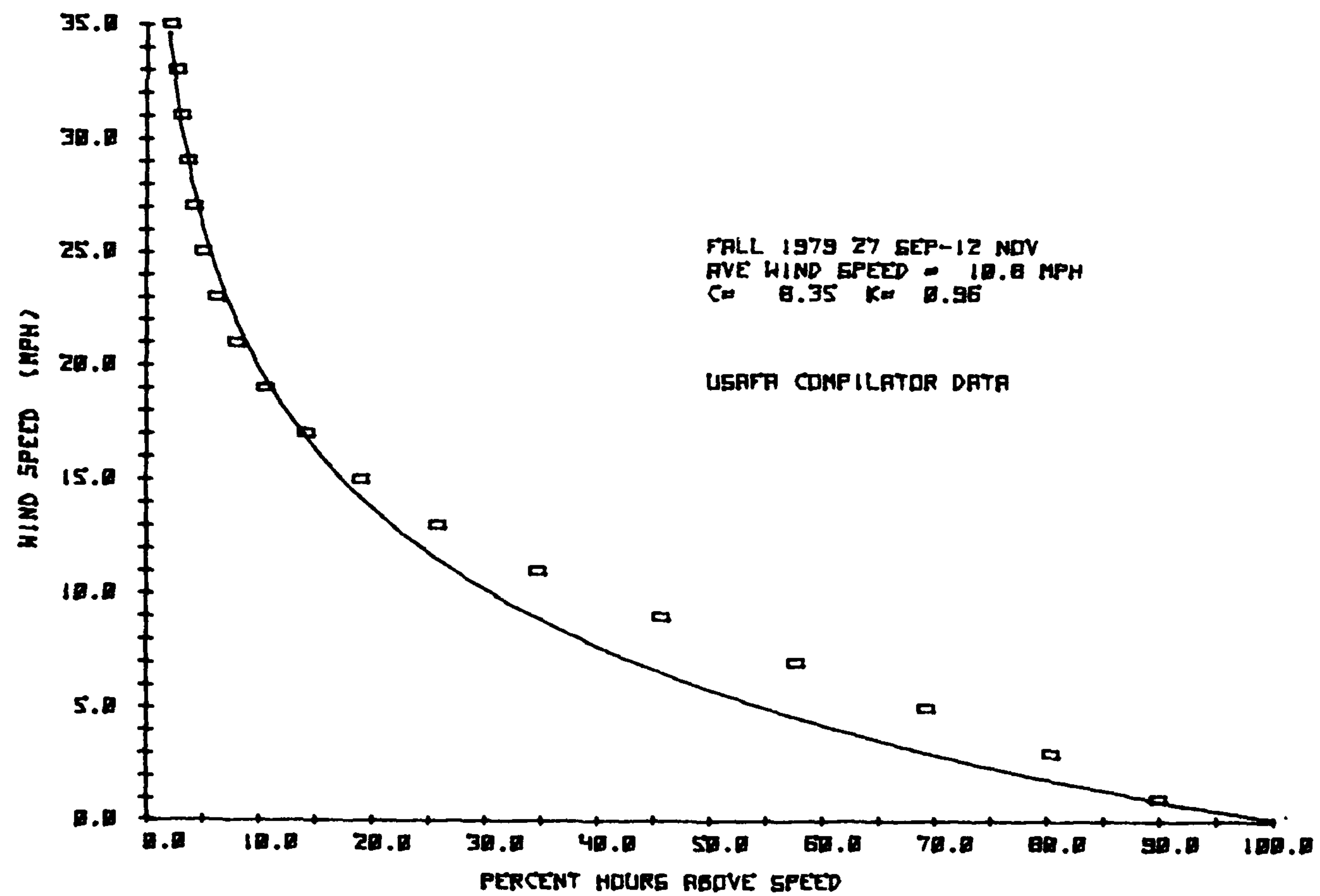



Figure A-29. Percent Time Above Speed,
Site #1, Fall 1979

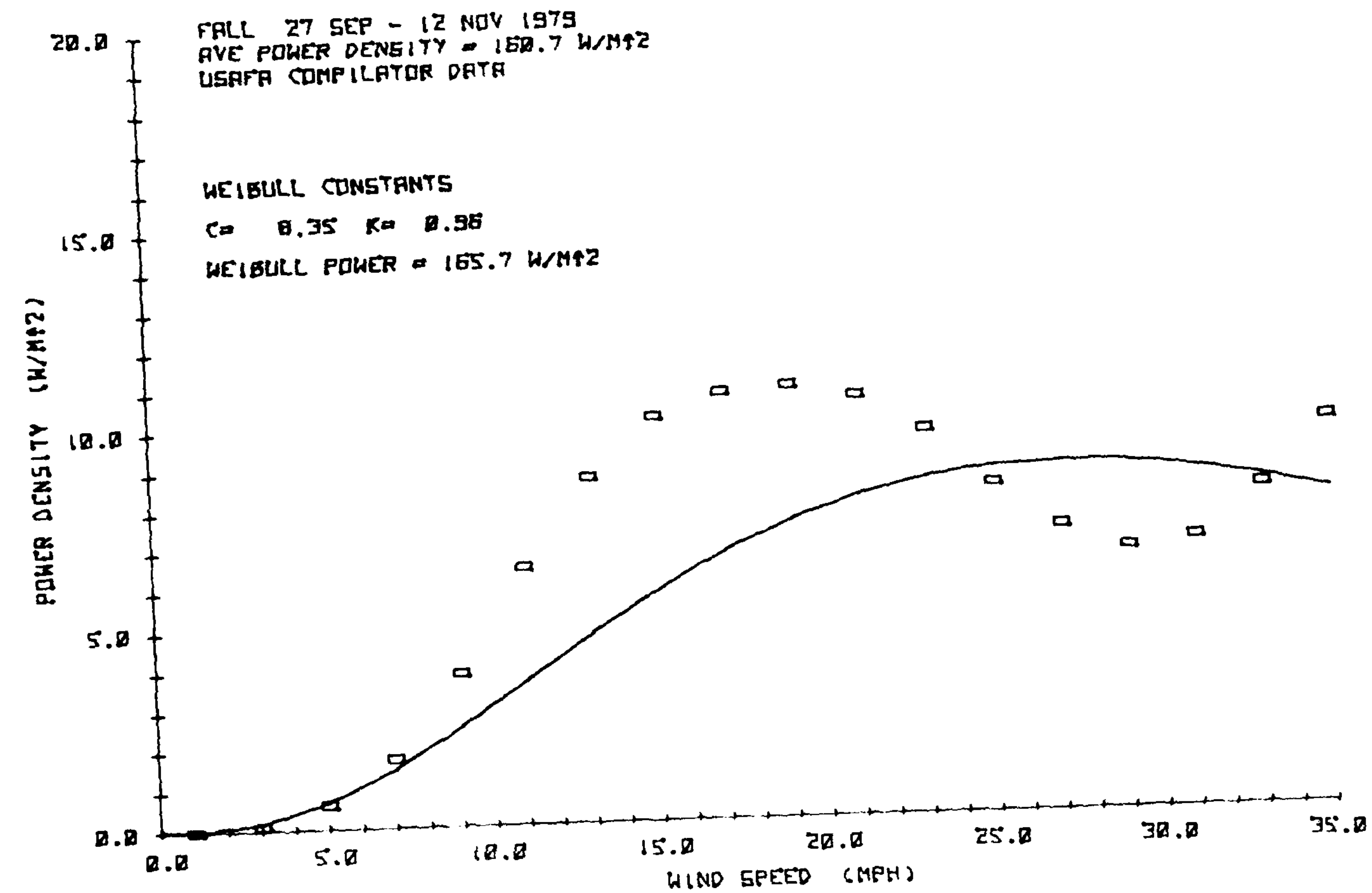



Figure A-30. Power Density, Site #1, Fall 1979

TABLE A-8: WIND SPEED OCCURRENCE VS. DIRECTION, SITE #1,
WINTER 1979-80

DATA COLLECTED [illegible] 80 20 NOV [illegible] FEB

| WIND SPEED (MPH) | TIME IN SECONDS FROM DIRECTION SE | E | NE | N | NW | W | SW | S | TOTAL TIME AT SPEED |
|---|---|---|---|---|---|---|---|---|---|
| 0- 2 | 63591 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2- 4 | 123731 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 85622 | 787061 |
| 4- 6 | 72589 | 82126 | [illegible] | [illegible] | [illegible] | [illegible] | 124585 | [illegible] | 904397 |
| 6- 8 | 37771 | 47998 | [illegible] | 66774 | [illegible] | [illegible] | [illegible] | 132648 | 907839 |
| 8- 10 | 17367 | 25412 | 238706 | 64261 | [illegible] | 81568 | 246168 | 91267 | 828809 |
| 10- 12 | 8329 | 14157 | 219272 | [illegible] | [illegible] | 74131 | 212557 | 56872 | 708739 |
| 12- 14 | 3471 | 3188 | 188419 | [illegible] | [illegible] | [illegible] | 168095 | 34283 | 581743 |
| 14- 16 | 1325 | 5403 | 153260 | [illegible] | [illegible] | 42023 | 120164 | 18827 | 455697 |
| 16- 18 | 545 | 3589 | 116749 | 26162 | [illegible] | [illegible] | 85819 | 10283 | 357934 |
| 18- 20 | 247 | 2129 | 84825 | [illegible] | 77099 | [illegible] | 63891 | 6197 | 285292 |
| 20- 22 | 83 | 1224 | 60195 | 16654 | [illegible] | 25559 | 44415 | [illegible] | 225402 |
| 22- 24 | 48 | 651 | 43900 | [illegible] | [illegible] | [illegible] | 28811 | 2017 | 179100 |
| 24- 26 | 14 | 430 | 31219 | 11250 | [illegible] | 17097 | 16309 | 1475 | 140702 |
| 26- 28 | 3 | 399 | [illegible] | 8710 | [illegible] | 13582 | 7883 | 609 | 107541 |
| 28- 30 | 2 | 264 | 12935 | 6694 | [illegible] | 11027 | 3285 | 315 | [illegible] |
| 30- 32 | 1 | 220 | 8426 | 5076 | 40851 | 8980 | 1452 | 97 | [illegible] |
| 32- 34 | 1 | 107 | 5851 | [illegible] | 34046 | 7668 | 643 | [illegible] | 51929 |
| 34- 36 | 1 | 98 | [illegible] | [illegible] | 27758 | 6648 | 337 | 8 | 41785 |
| 36- 38 | 0 | 89 | 3015 | [illegible] | 22102 | 5605 | 206 | [illegible] | 32945 |
| 38- 40 | 0 | 61 | [illegible] | 1390 | 17066 | 4598 | 149 | 0 | 25076 |
| 40- 42 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 114 | 2 | 18940 |
| 42 44 | 0 | 16 | [illegible] | [illegible] | [illegible] | 3131 | 59 | 0 | 14464 |
| 44- 46 | 0 | [illegible] | [illegible] | 435 | [illegible] | [illegible] | 50 | 0 | 11316 |
| 46- 48 | 0 | 7 | 125 | 307 | [illegible] | 2219 | 39 | 0 | 9172 |
| 48- 50 | 0 | 3 | 47 | [illegible] | 5055 | 1812 | 16 | 0 | 7161 |
| 50- 52 | 0 | 1 | [illegible] | 149 | 3895 | 1421 | 22 | 0 | 5506 |
| 52- 54 | 0 | 0 | 2 | [illegible] | 3041 | 1095 | 10 | 0 | 4245 |
| 54- 56 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 3 | 0 | 3018 |
| 56- 58 | 0 | 0 | 2 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | [illegible] |
| 58- 60 | 0 | 0 | 1 | 30 | [illegible] | [illegible] | [illegible] | 0 | 1492 |
| 60- 62 | 0 | 0 | 2 | 15 | [illegible] | 246 | 0 | 0 | 1000 |
| 62- 64 | 0 | 0 | 0 | 36 | [illegible] | [illegible] | 0 | 0 | [illegible] |

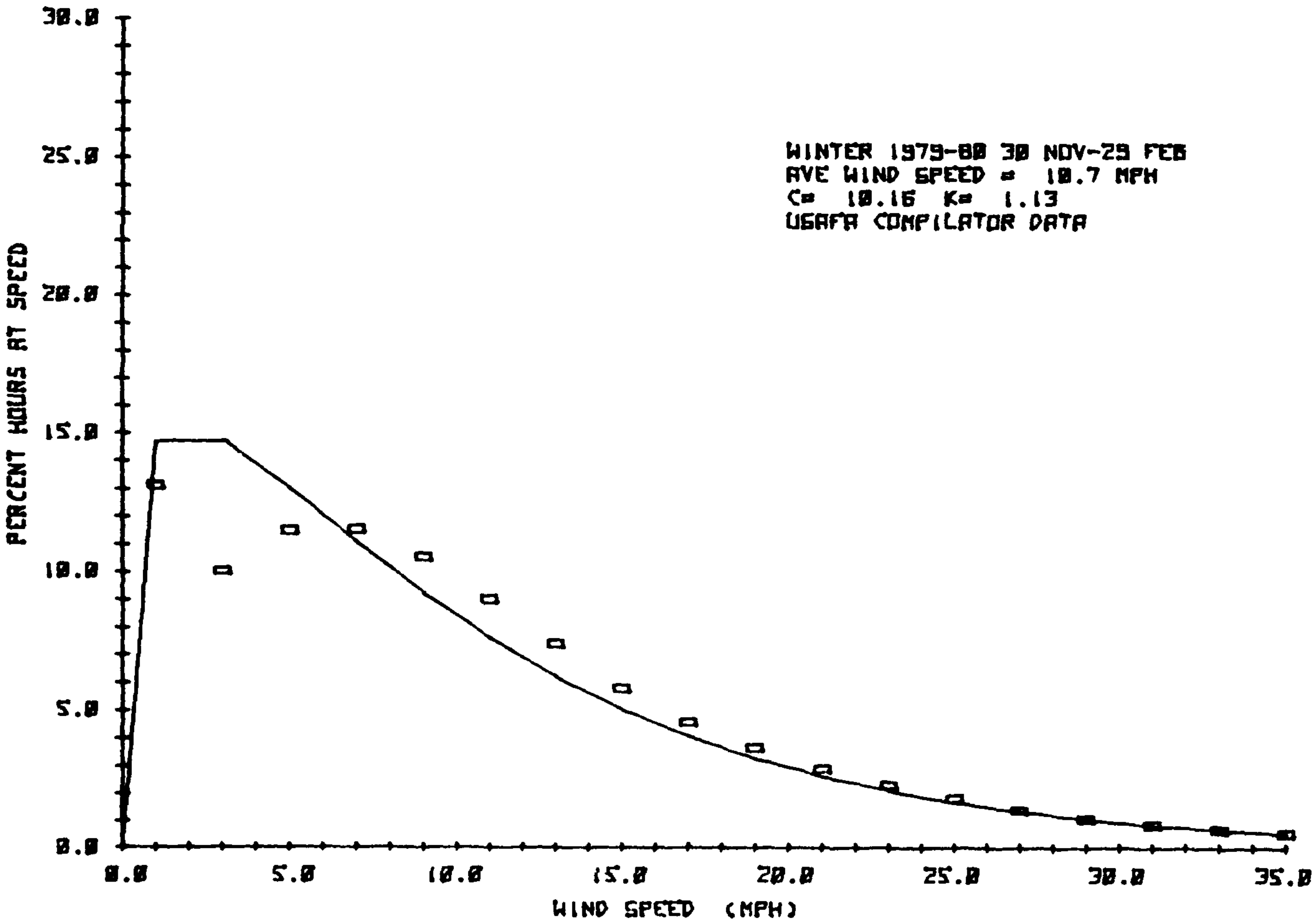



Figure A-31. Percent Time at Speed,
Site #1, Winter 1979-80

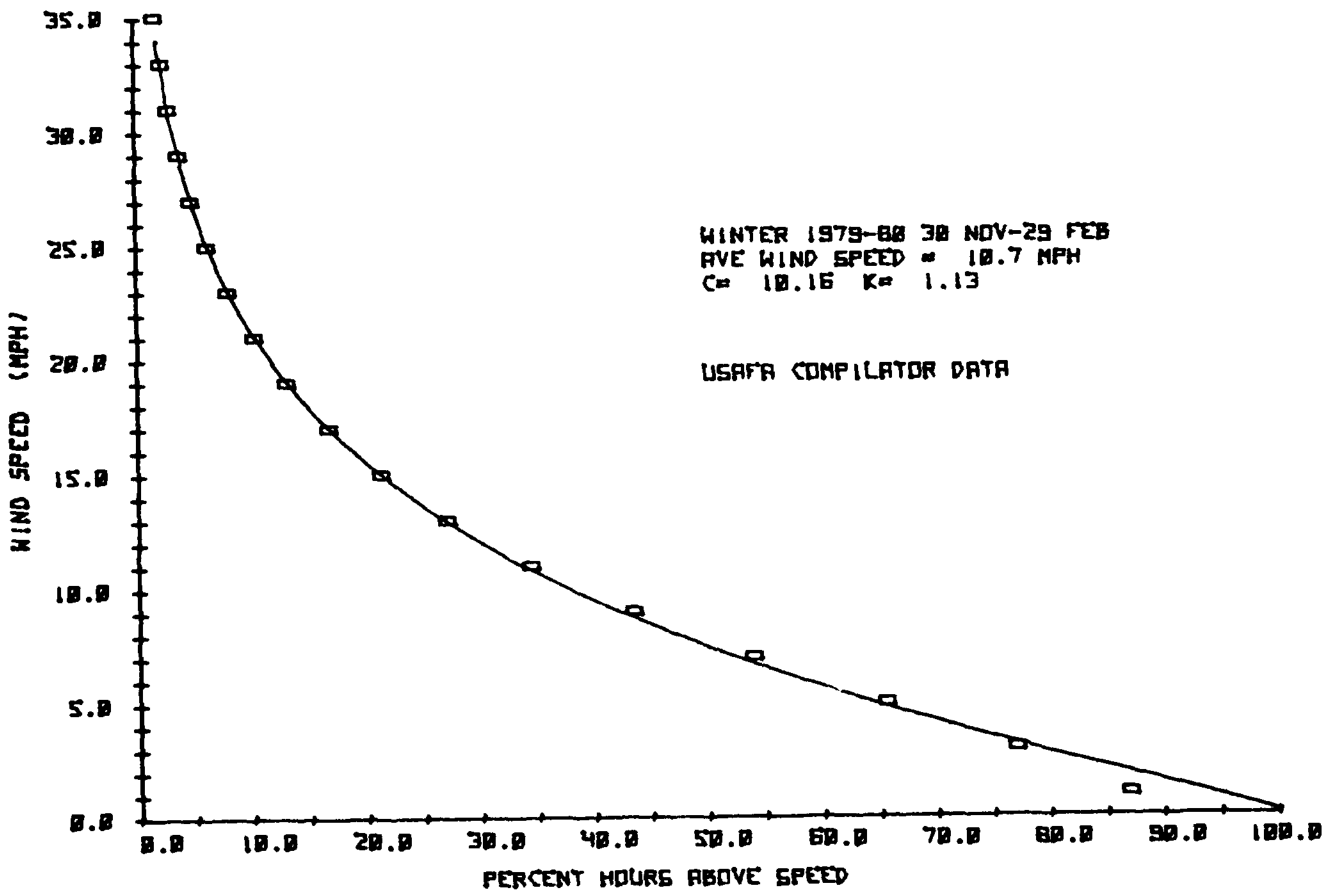



Figure A-32. Percent Time Above Speed,
Site #1, Winter 1979-80

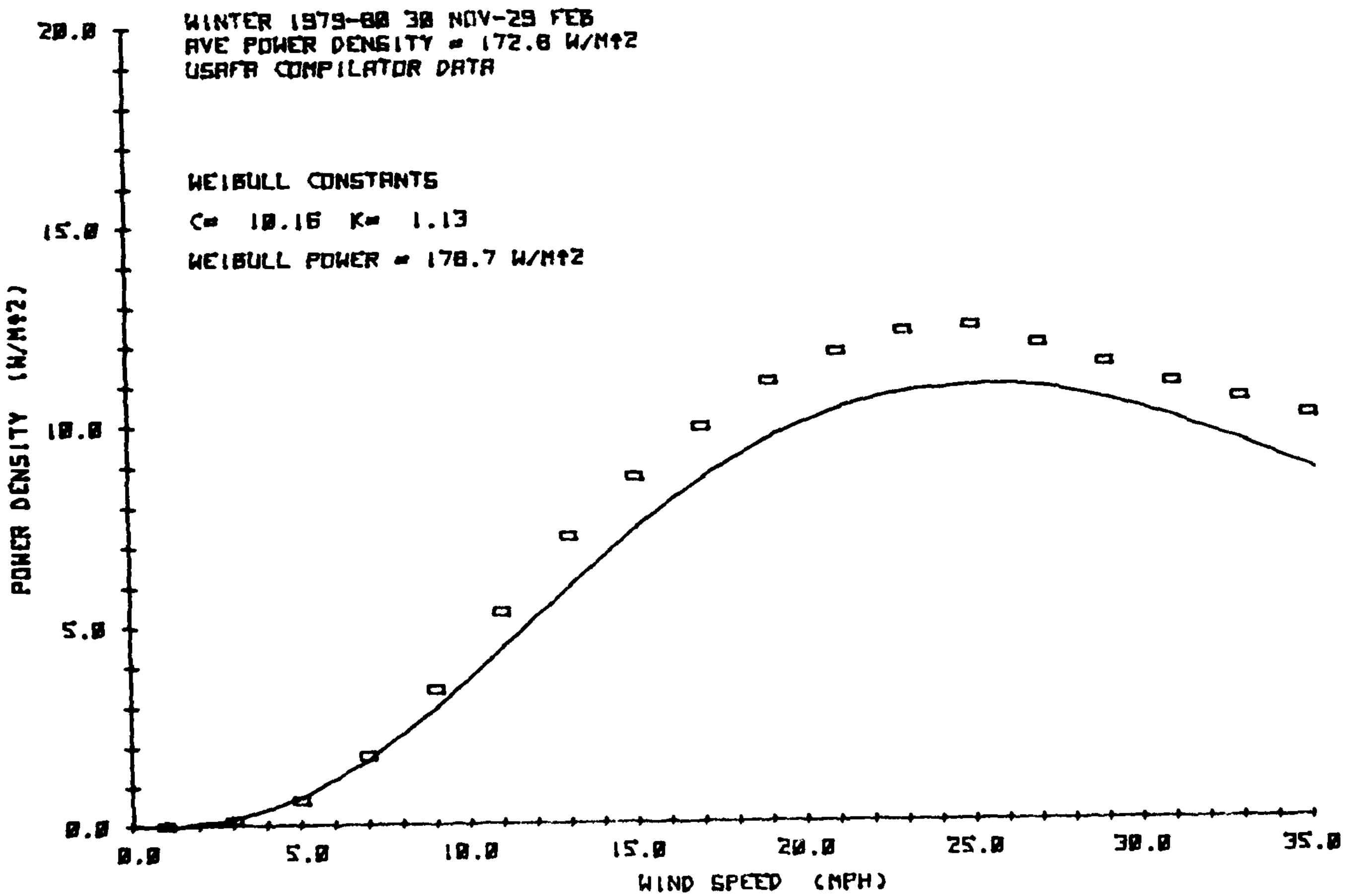



Figure A-33. Power Density,
Site #1, Winter 1979-80

TABLE A-2: WIND SPEED OCCURRENCE VS. DIRECTION, SITE #1, SPRING 1979-80

| WIND SPEED (MPH) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | TOTAL TIME IN SPEED |
|---|---|---|---|---|---|---|---|---|---|
| 0- 2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2- 4 | 4443 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 44041 | 493202 |
| 4- 6 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 54064 | [illegible] |
| 6- 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8- 10 | [illegible] | [illegible] | [illegible] | 44474 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 10- 12 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 12- 14 | 2506 | 35652 | 136300 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14- 16 | 1665 | 34268 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16- 18 | 921 | 33981 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 19718 | [illegible] |
| 18- 20 | 642 | 33007 | [illegible] | 25411 | 4401 | [illegible] | [illegible] | 13762 | [illegible] |
| 20- 22 | 333 | 23899 | [illegible] | 30280 | [illegible] | [illegible] | [illegible] | 9211 | 318602 |
| 22- 24 | 154 | 14781 | [illegible] | 16017 | [illegible] | [illegible] | [illegible] | 5139 | 219520 |
| 24- 26 | 72 | 8509 | [illegible] | 14891 | 25056 | [illegible] | [illegible] | [illegible] | 152479 |
| 26- 28 | 26 | 4141 | [illegible] | [illegible] | 19297 | [illegible] | [illegible] | 1321 | 103014 |
| 28- 30 | 11 | 1848 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 727 | [illegible] |
| 30- 32 | 9 | 923 | [illegible] | 5136 | [illegible] | [illegible] | [illegible] | 485 | 53363 |
| 32- 34 | 4 | 417 | [illegible] | 3494 | [illegible] | 8971 | [illegible] | [illegible] | 37942 |
| 34- 36 | 0 | 162 | [illegible] | [illegible] | 8841 | [illegible] | [illegible] | 140 | 26599 |
| 36- 38 | 0 | 58 | [illegible] | [illegible] | 7364 | [illegible] | [illegible] | [illegible] | 18477 |
| 38- 40 | 0 | [illegible] | [illegible] | 1032 | 5714 | [illegible] | [illegible] | [illegible] | [illegible] |
| 40- 42 | 0 | 5 | [illegible] | [illegible] | 4606 | [illegible] | 46 | [illegible] | [illegible] |
| 42- 44 | 0 | 1 | [illegible] | [illegible] | 3444 | [illegible] | [illegible] | 7 | [illegible] |
| 44- 46 | 0 | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 4461 |
| 46- 48 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48- 50 | 0 | 0 | [illegible] | 105 | [illegible] | 438 | [illegible] | 0 | [illegible] |
| 50- 52 | 0 | 0 | [illegible] | [illegible] | [illegible] | 335 | [illegible] | 0 | [illegible] |
| 52- 54 | 0 | 0 | 17 | [illegible] | [illegible] | 191 | 1 | 0 | 854 |
| 54- 56 | 0 | 0 | 8 | [illegible] | [illegible] | 118 | 0 | 0 | 485 |
| 56- 58 | 0 | 0 | [illegible] | [illegible] | [illegible] | 61 | 0 | 0 | [illegible] |
| 58- 60 | 0 | 0 | [illegible] | | [illegible] | 34 | [illegible] | [illegible] | [illegible] |
| 60- 62 | 0 | 0 | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

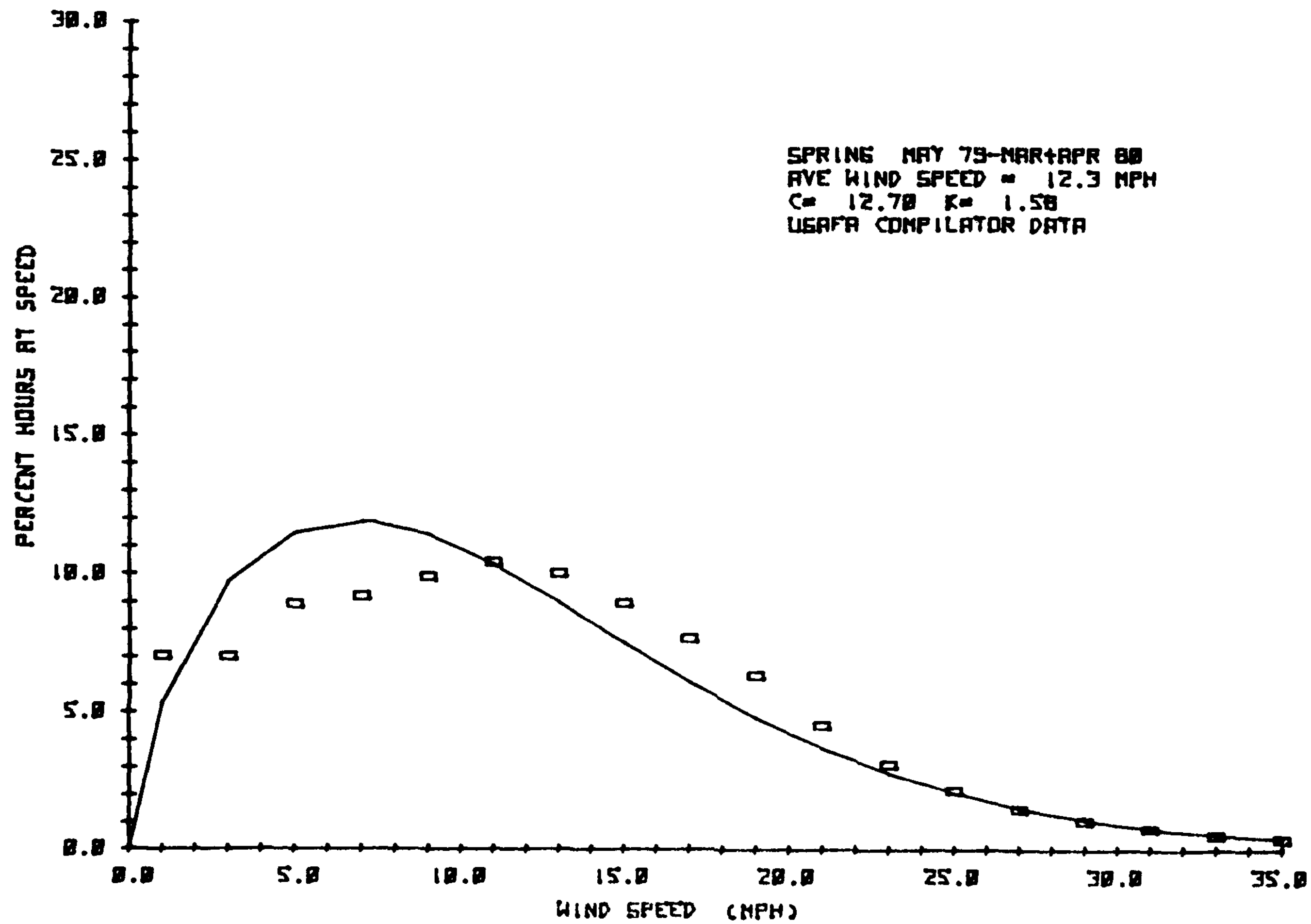



Figure A-34. Percent Time at Speed,
Site #1, Spring 1979-80

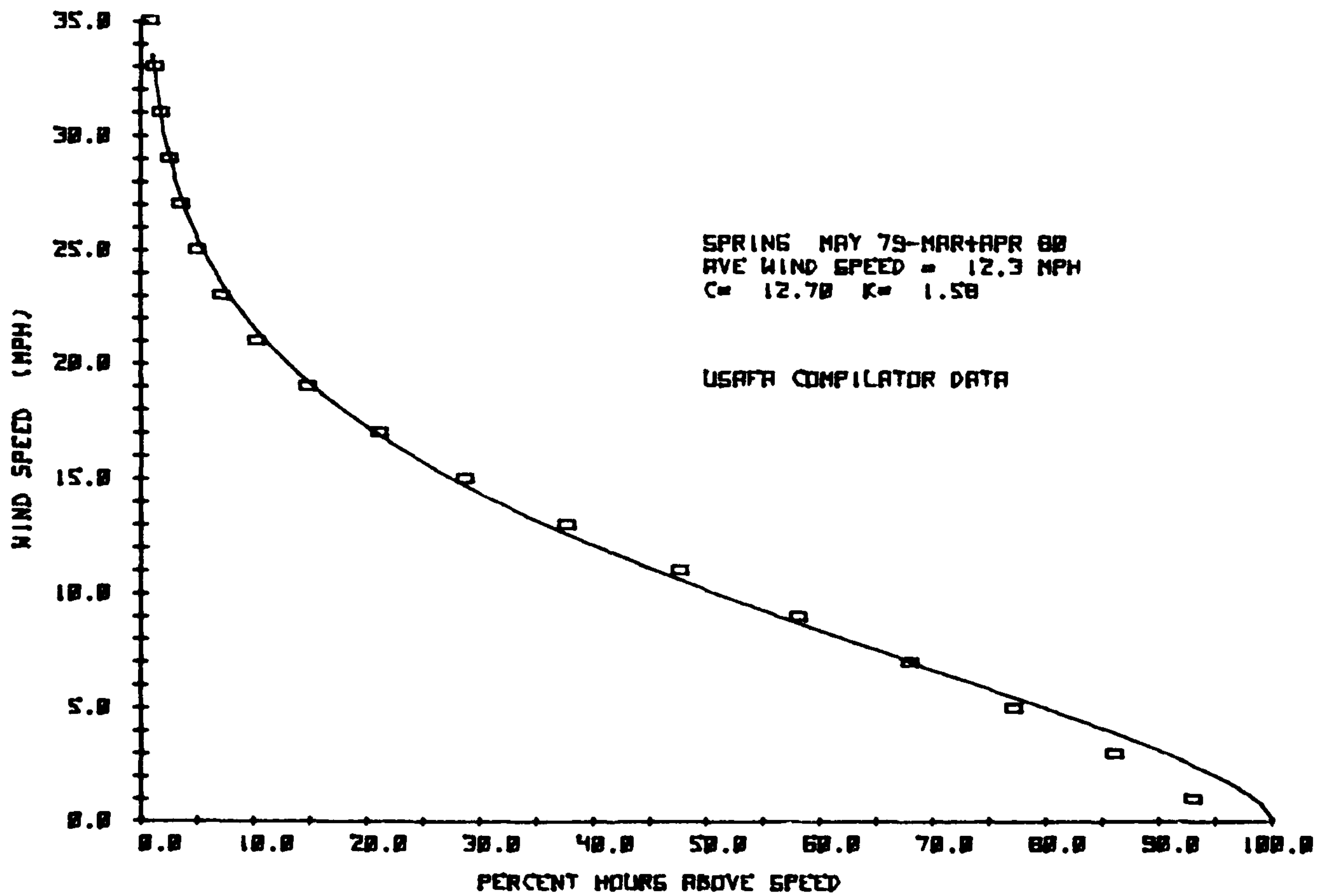



Figure A-35. Percent Time Above Speed, Site #1, Spring 1979-80

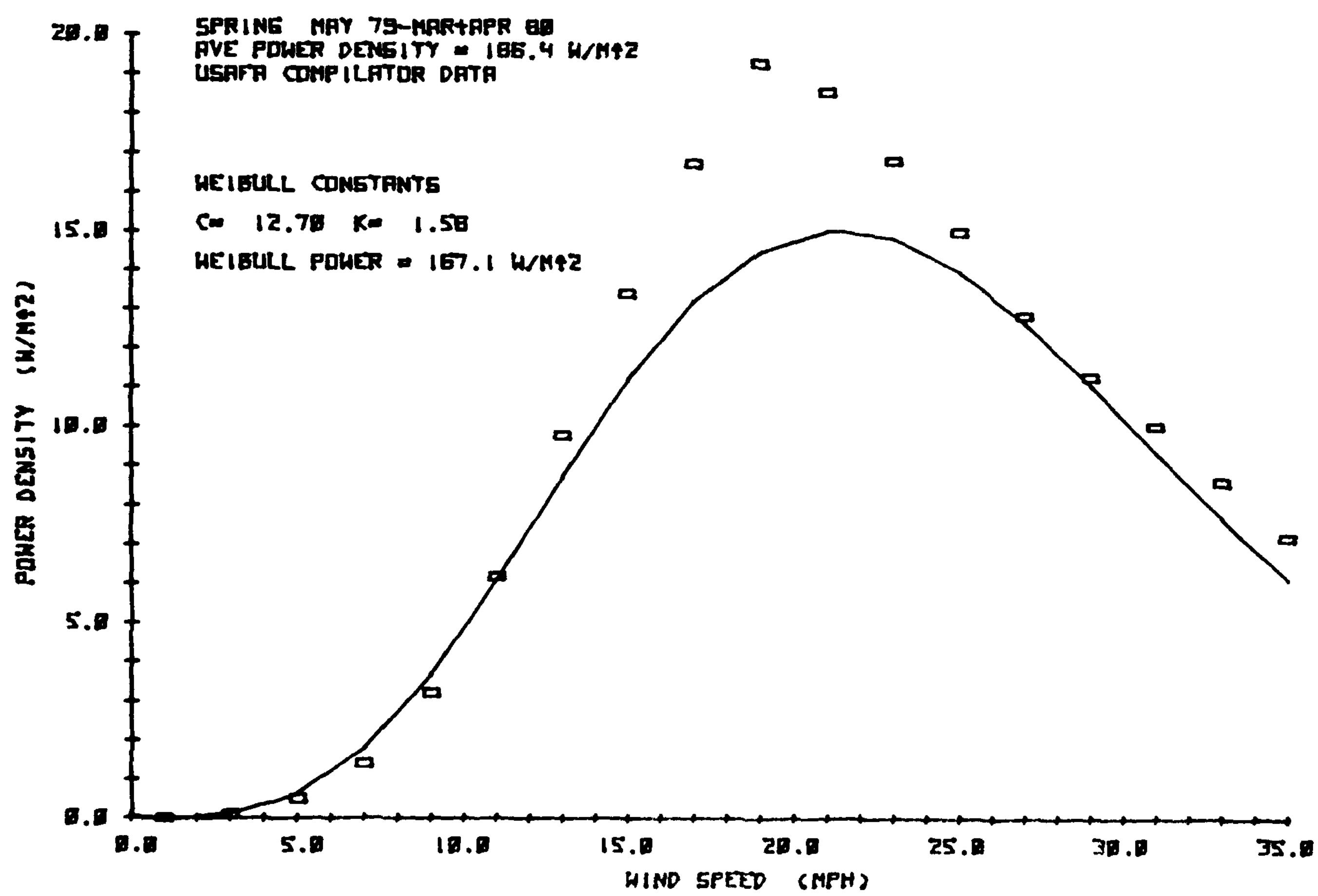



Figure A-36. Power Density,
Site #1, Spring 1979-80

TABLE A-19. WIND SPEED OCCURRENCE VS. DIRECTION, [illegible], APRIL 1979-19[illegible]

| WIND SPEED (MPH) | SE | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] TIME AT SPEED |
|---|---|---|---|---|---|---|---|---|
| 0- 2 | 120964 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2- 4 | 222596 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 4- 6 | 130104 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 6- 8 | 69247 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8- 10 | 33517 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 10- 12 | 16159 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 12- 14 | 7281 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14- 16 | 3414 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16- 18 | 1566 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18- 20 | 918 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20- 22 | 432 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22- 24 | 205 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24- 26 | 91 | 4162 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 8541 |
| 26- 28 | 29 | 4530 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28- 30 | 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30- 32 | 10 | 1204 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32- 34 | 5 | 554 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 34- 36 | 0 | 382 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 36- 38 | 0 | 159 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 38- 40 | 0 | 98 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40- 42 | 0 | 52 | [illegible] | [illegible] | [illegible] | 6459 | [illegible] | [illegible] |
| 42- 44 | 0 | 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 44- 46 | 0 | 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 46- 48 | 0 | 12 | [illegible] | [illegible] | [illegible] | 3011 | [illegible] | [illegible] |
| 48- 50 | 0 | 4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50- 52 | 0 | 2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52- 54 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54- 56 | 0 | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56- 58 | 0 | 0 | [illegible] | [illegible] | [illegible] | 610 | [illegible] | [illegible] |
| 58- 60 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60- 62 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

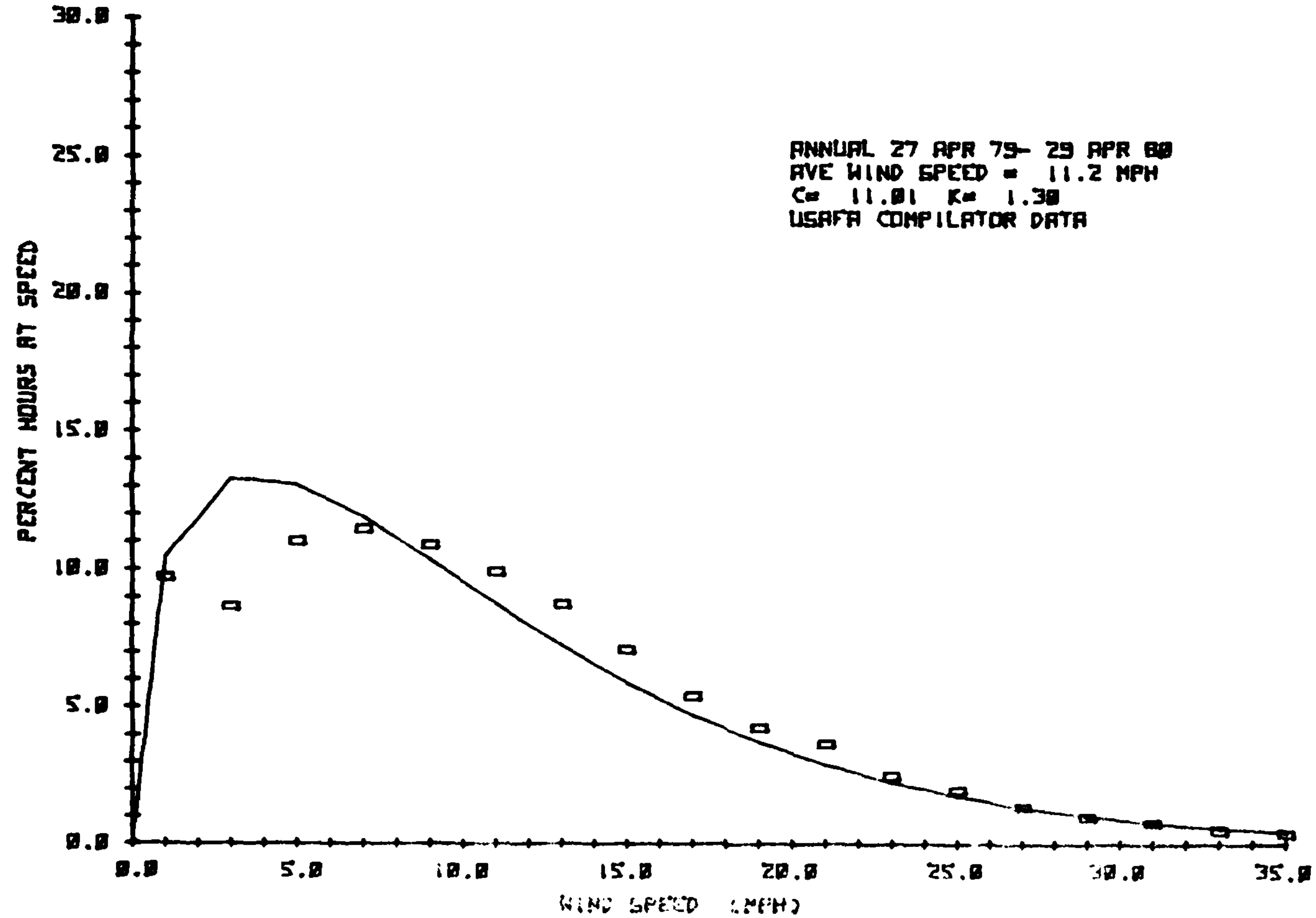



Figure A-37. Percent Time at Speed,
Site #1, April 1979-April 1980

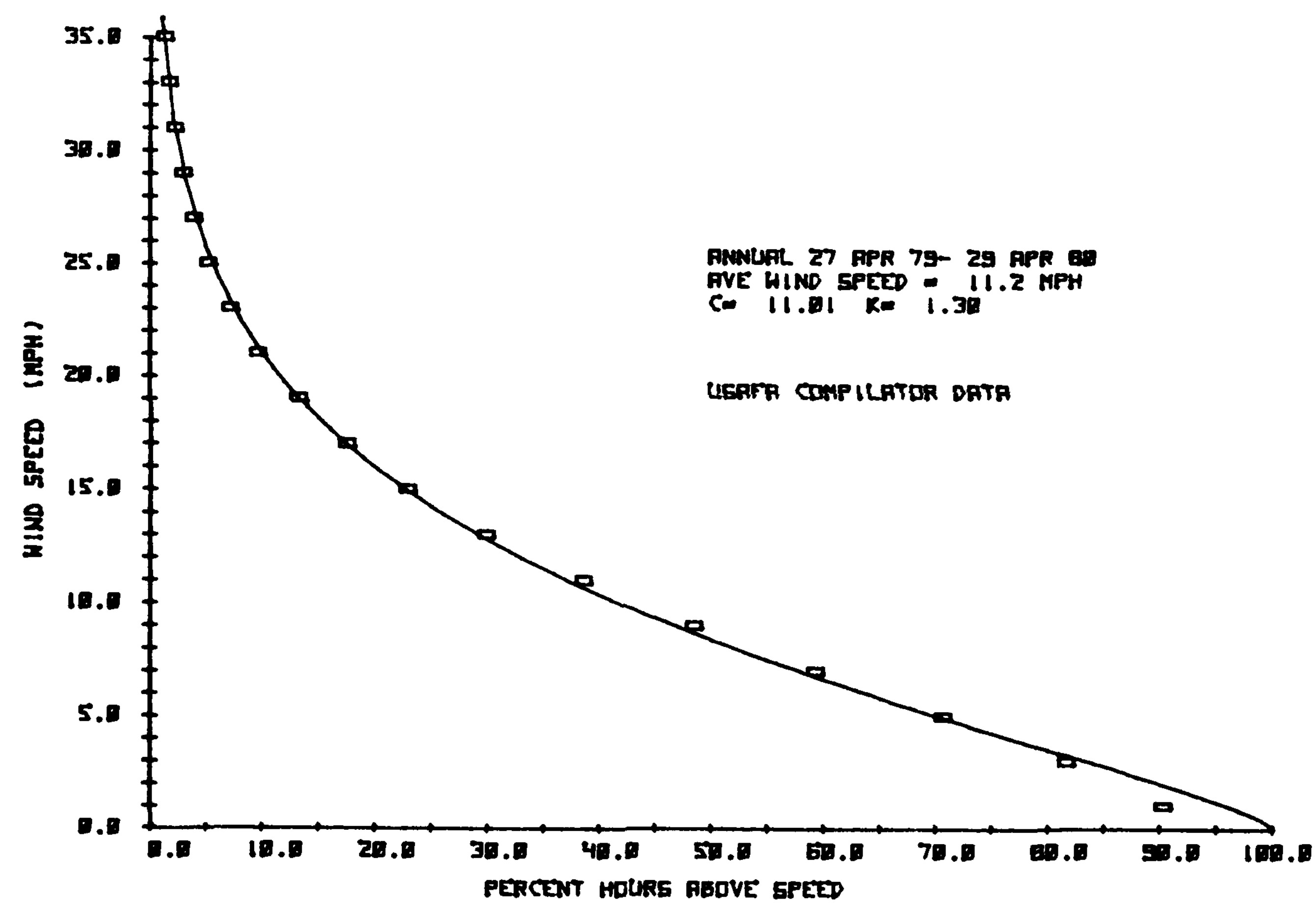



Figure A-38. Percent Time Above Speed,
Site #1, April 1979-April 1980

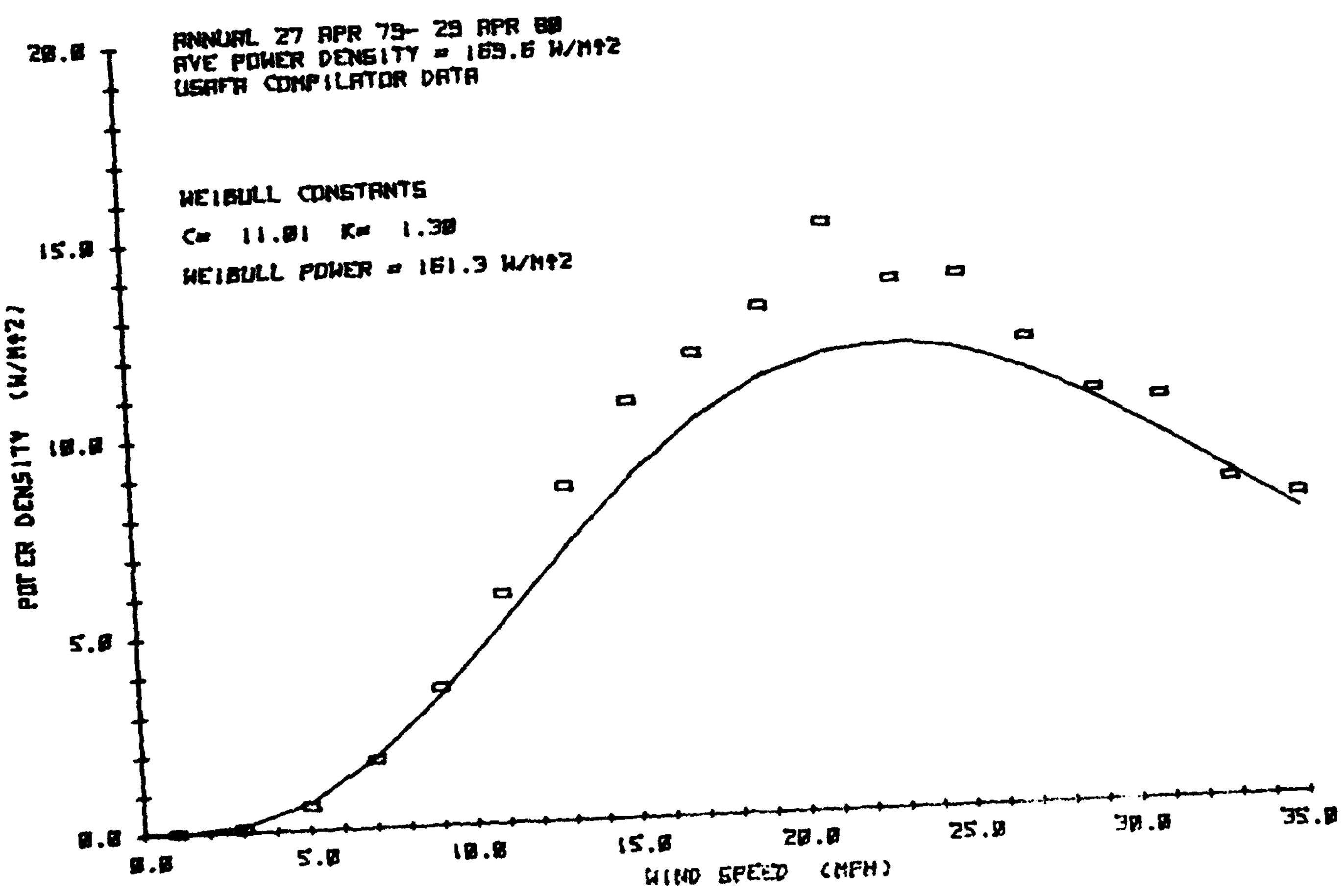



Figure A-39. Power Density,
Site #1, April 1979-April 1980

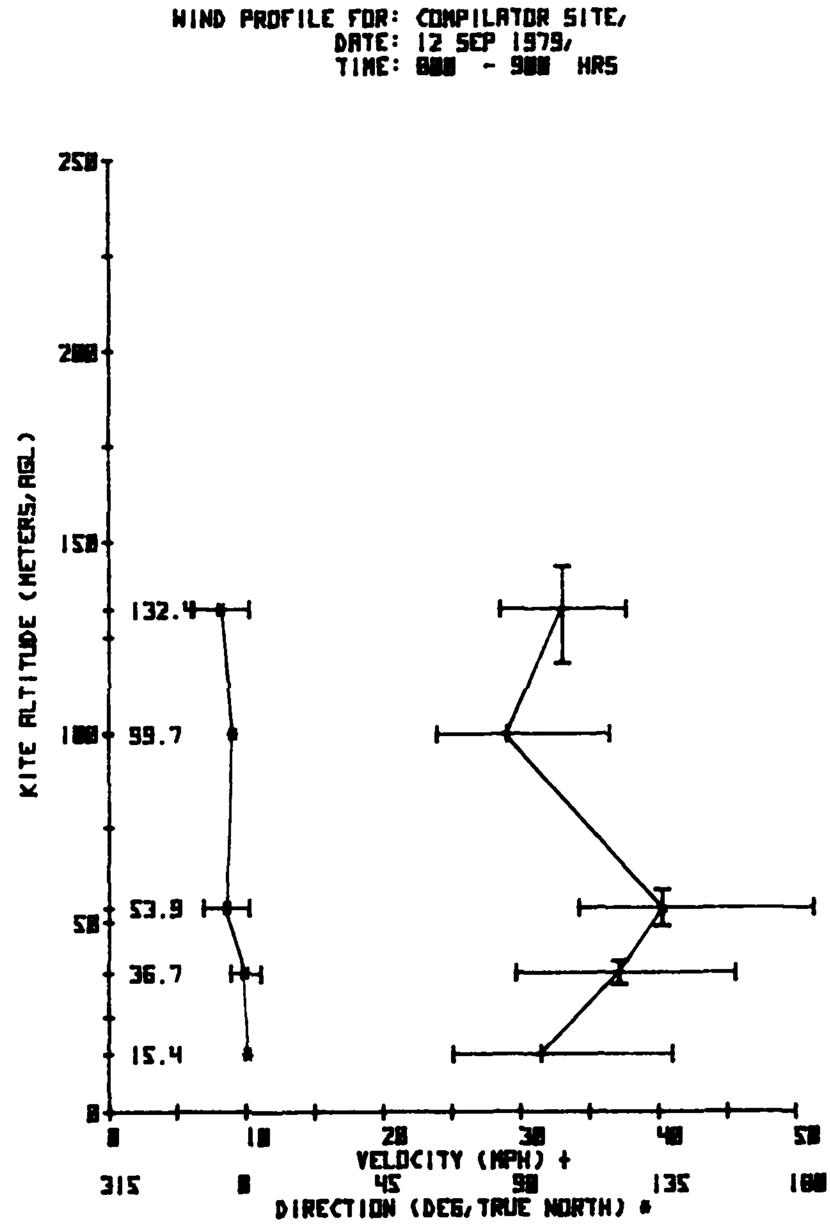



Figure A-40. TALA Record No. 1, Site #1

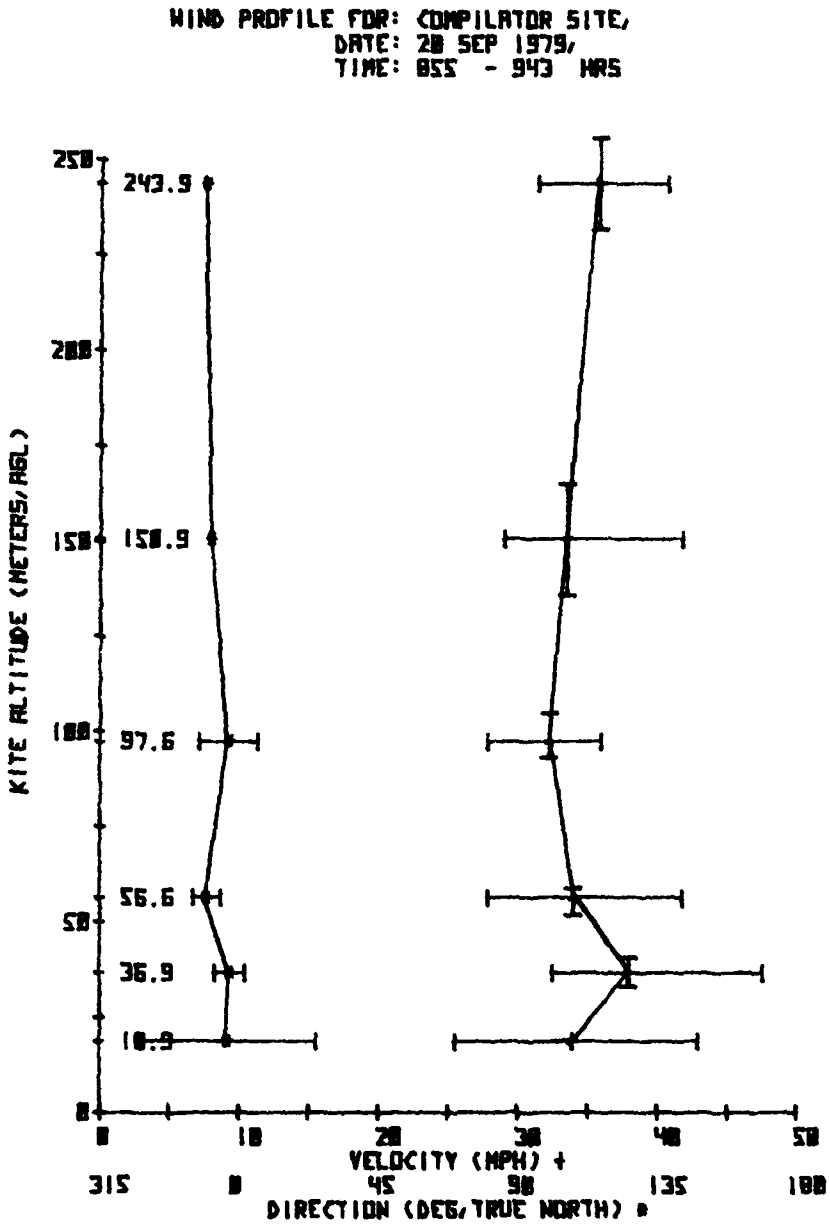



Figure A-41. TALA Record No. 2, Site #1

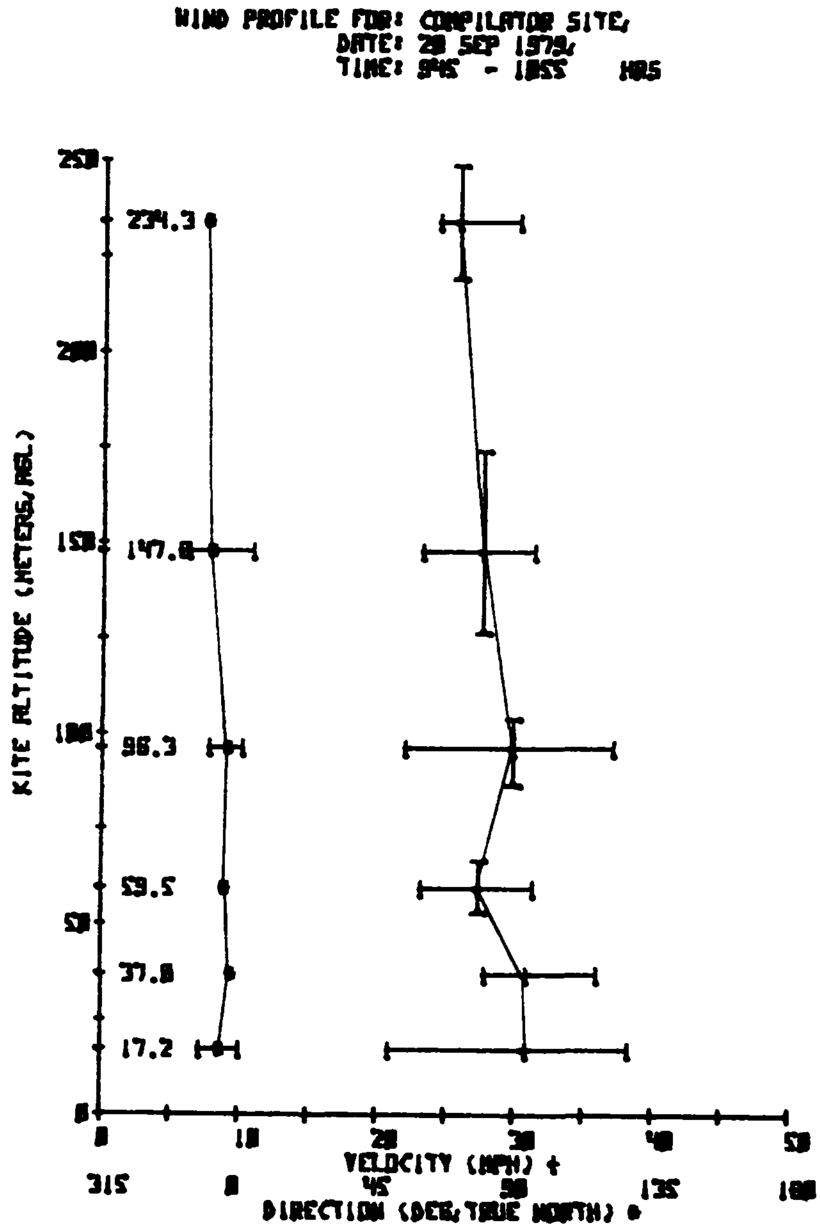



Figure A-42. TALA Record No. 3, Site #1

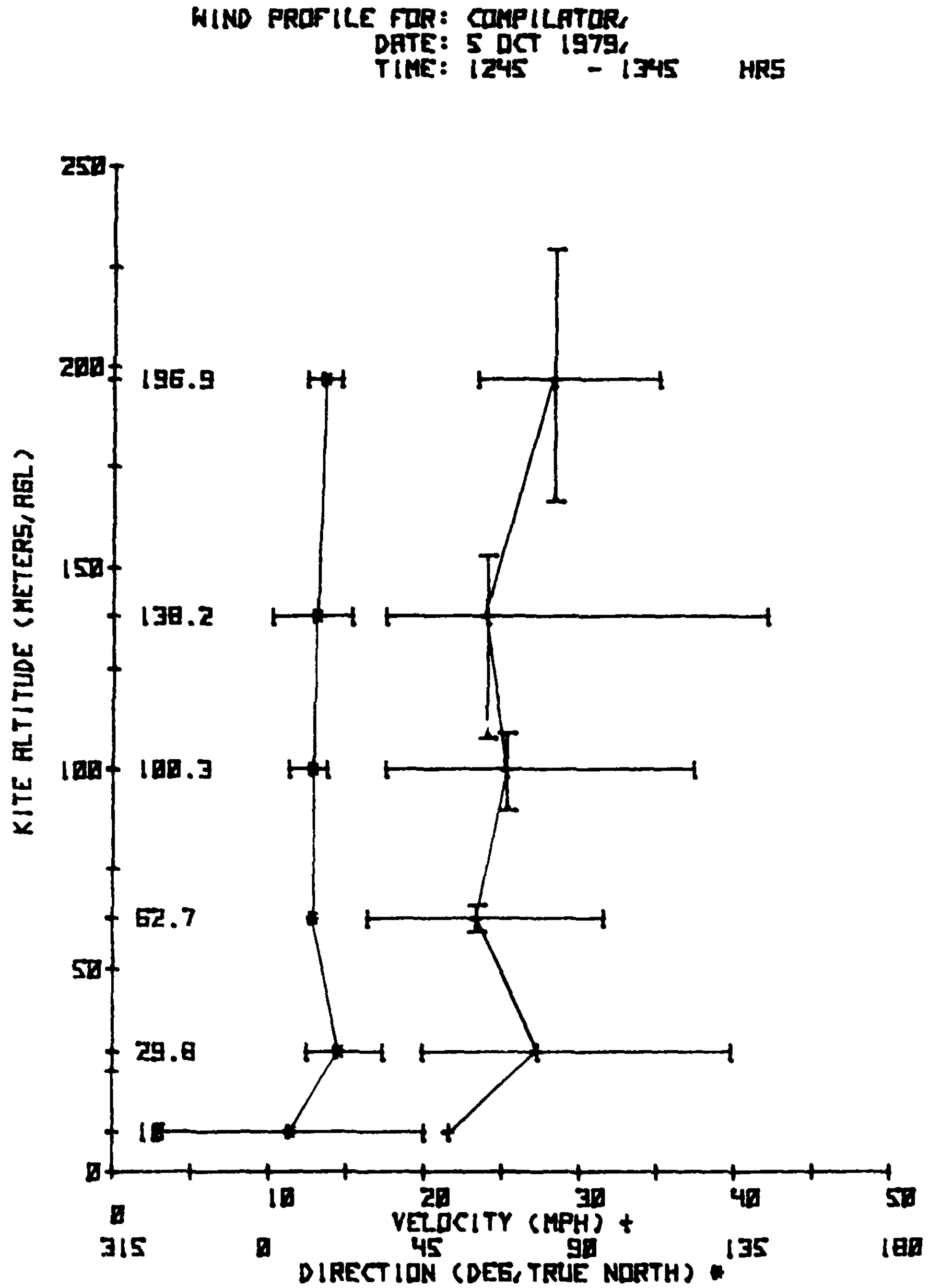



Figure A-43. TALA Record No. 4, Site #1

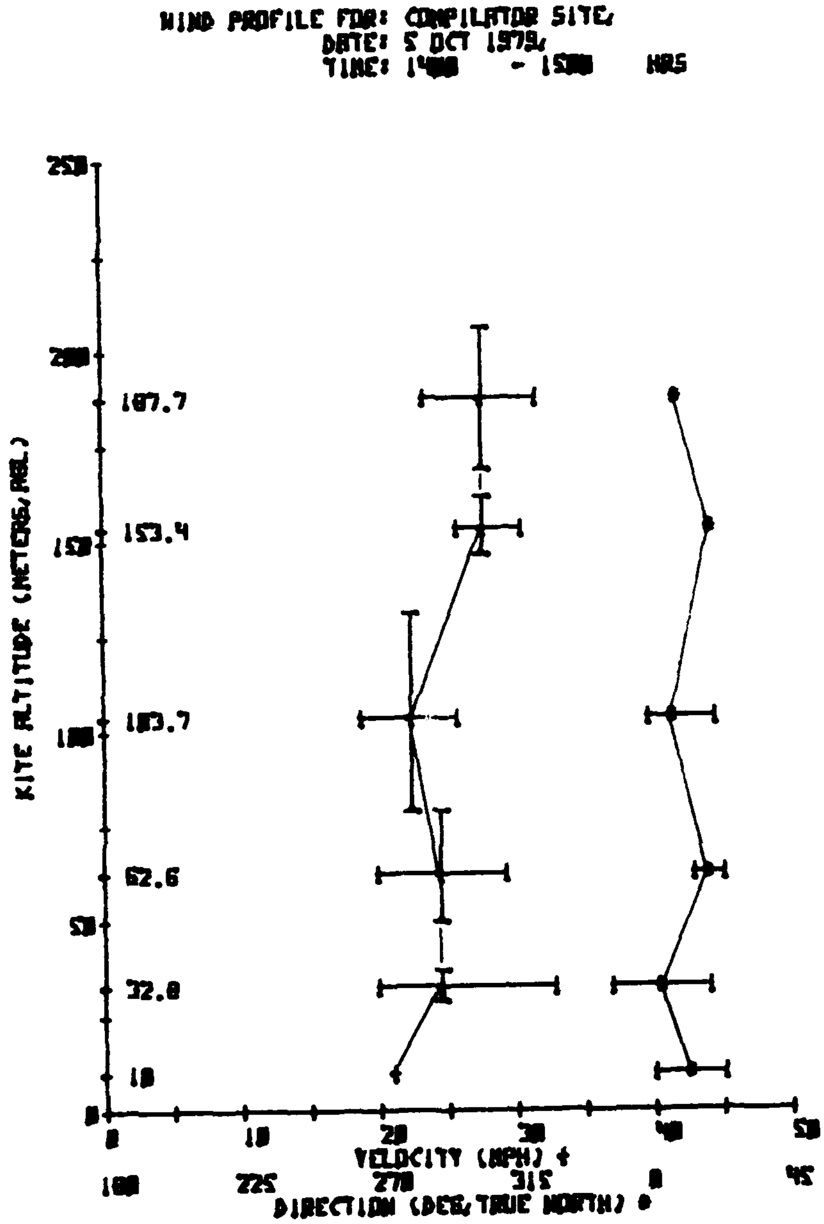



Figure A-44. TALA Record No. 5, Site #1

WIND PROFILE FOR: NORTH ACCUMULATOR/
DATE: 12 SEP 1979/
TIME: 1224 - 1306 HRS

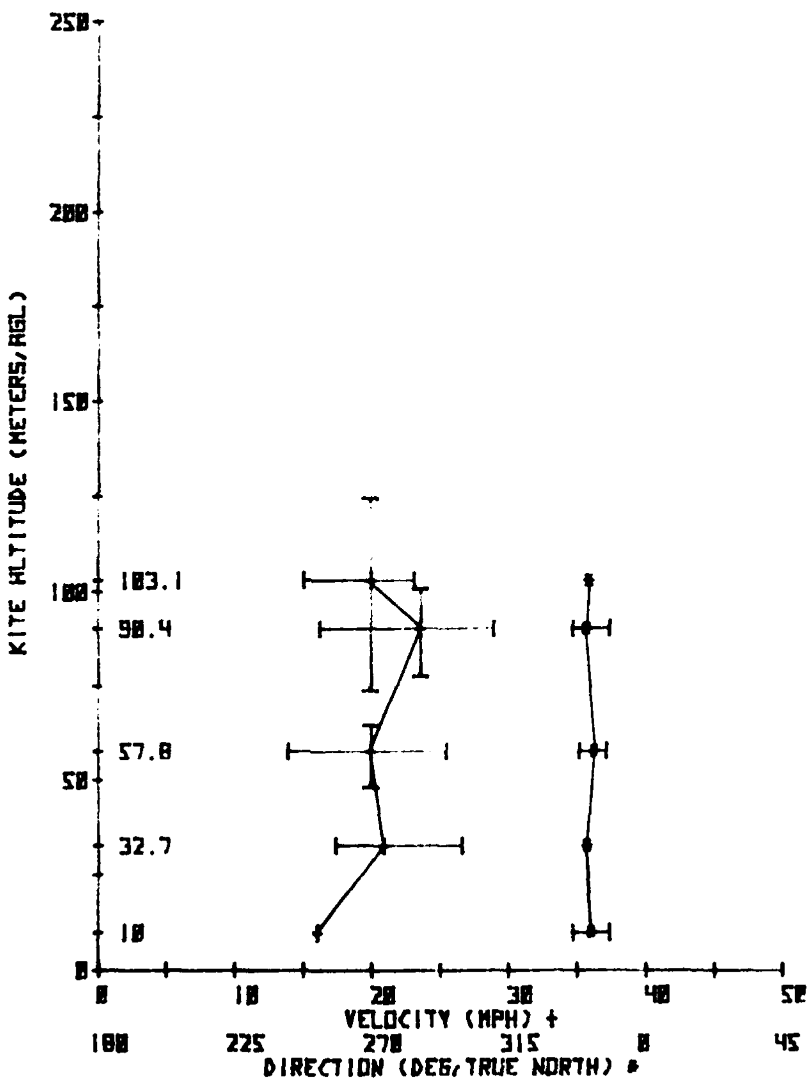



Figure A-45. TALA Record No. 1, Site #2

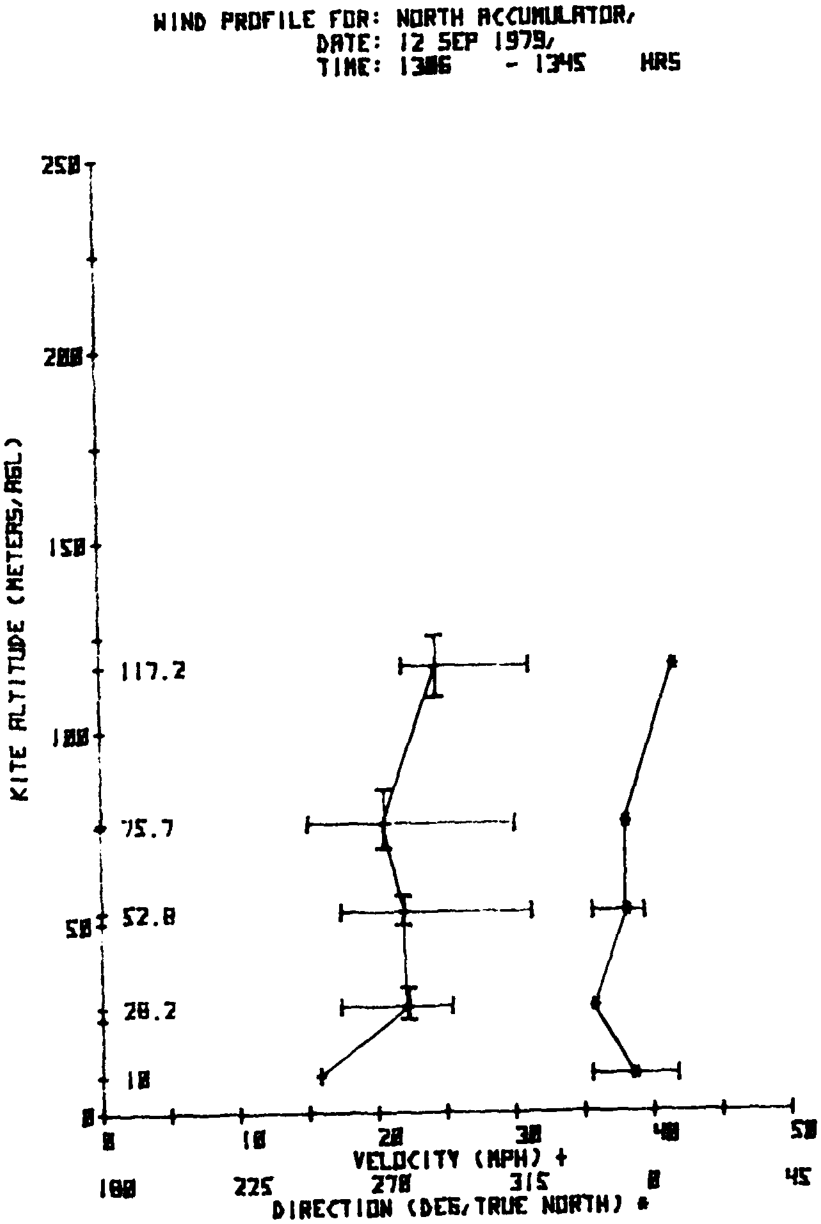



Figure A-46. TALA Record No. 2, Site #2

WIND PROFILE FOR: NORTH ACCUMULATOR/
DATE: 13 SEP 1979/
TIME: 1149 - 1237 HRS

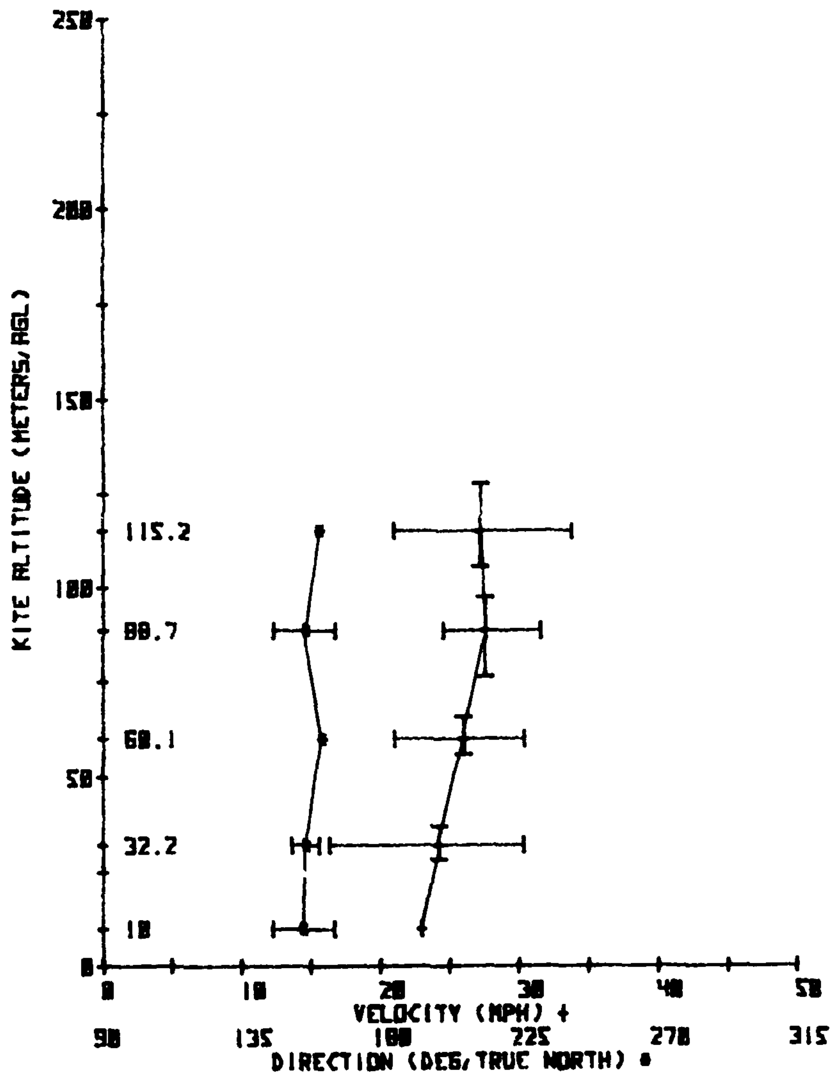



Figure A-47. TALA Record No. 3, Site #2

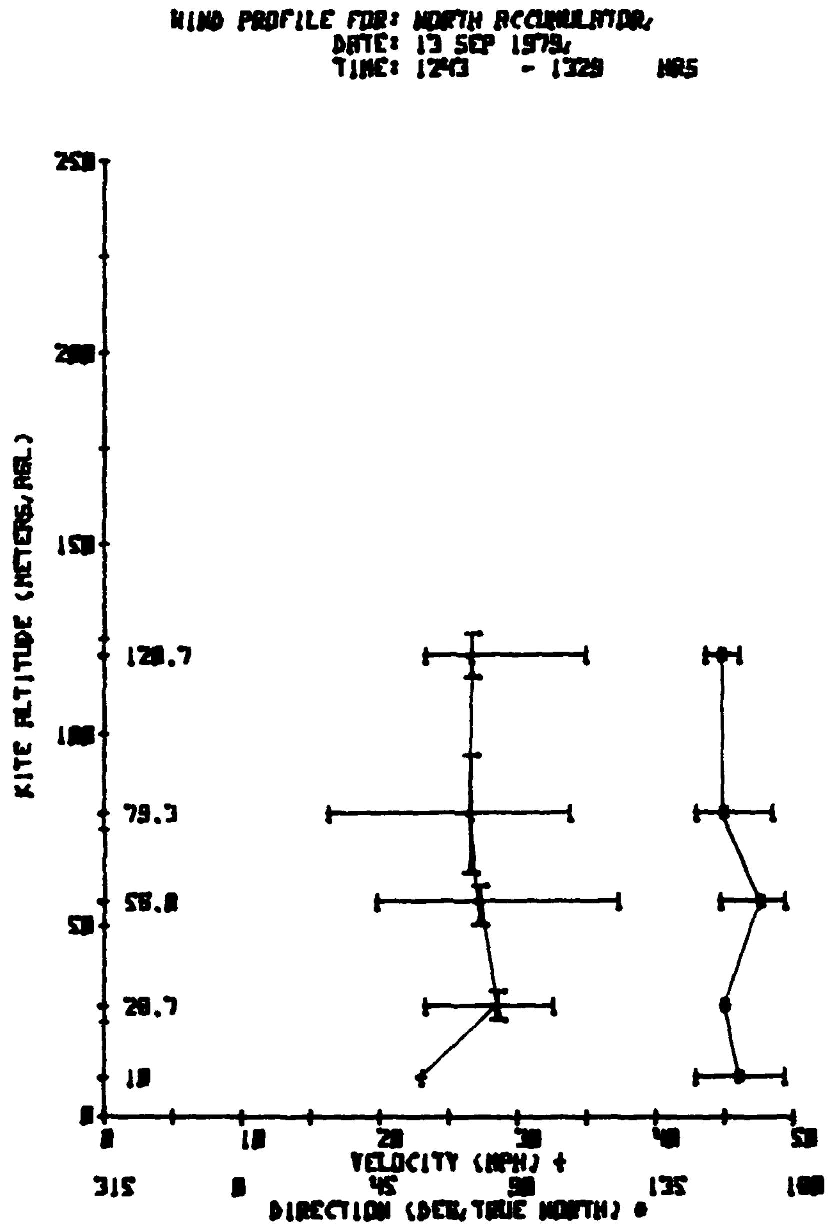



Figure A-48. TALA Record No. 4, Site #2

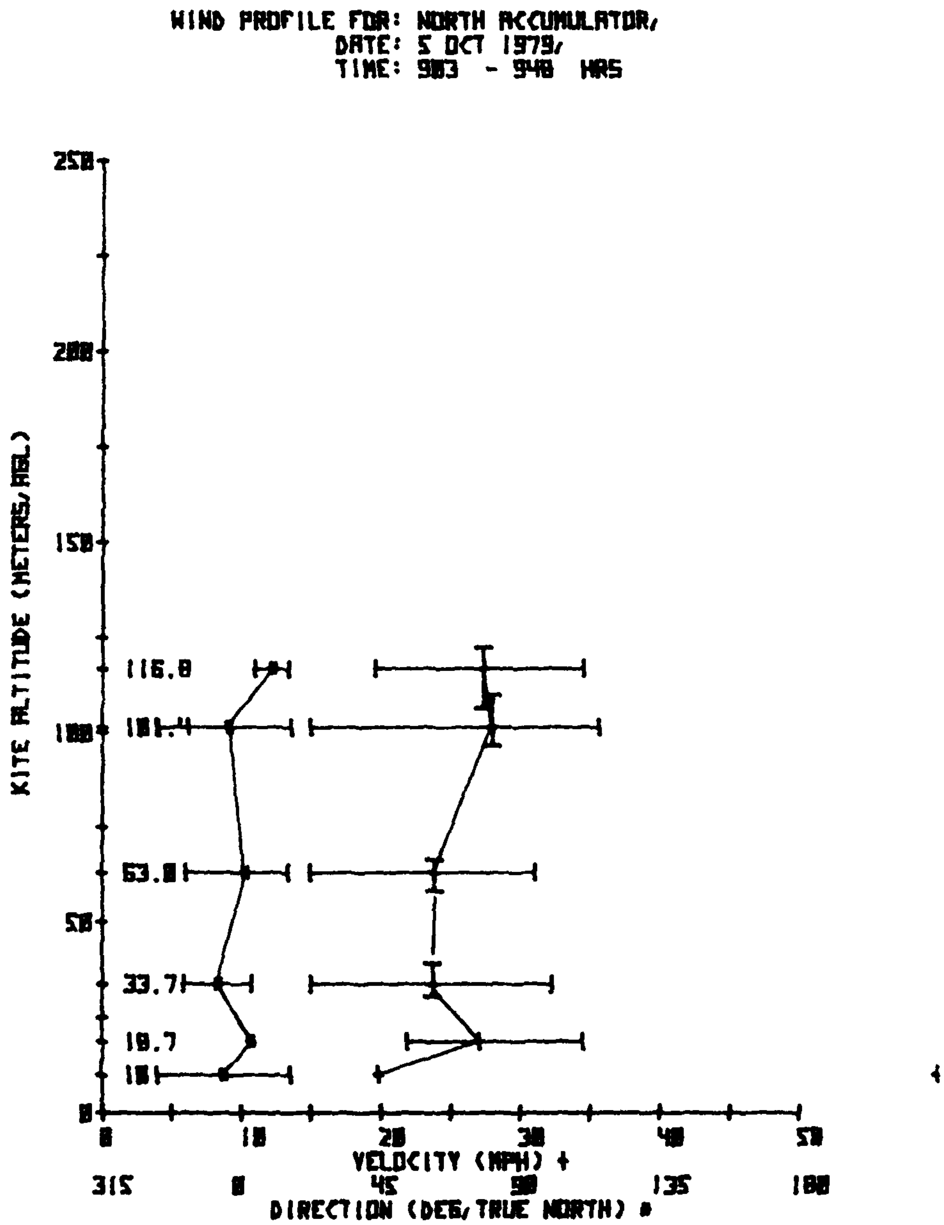



Figure A-49. TALA Record No. 5, Site #2

WIND PROFILE FOR: NORTH ACCUMULATOR,
DATE: 5 OCT 1979,
TIME: 1006 - 1044 HRS

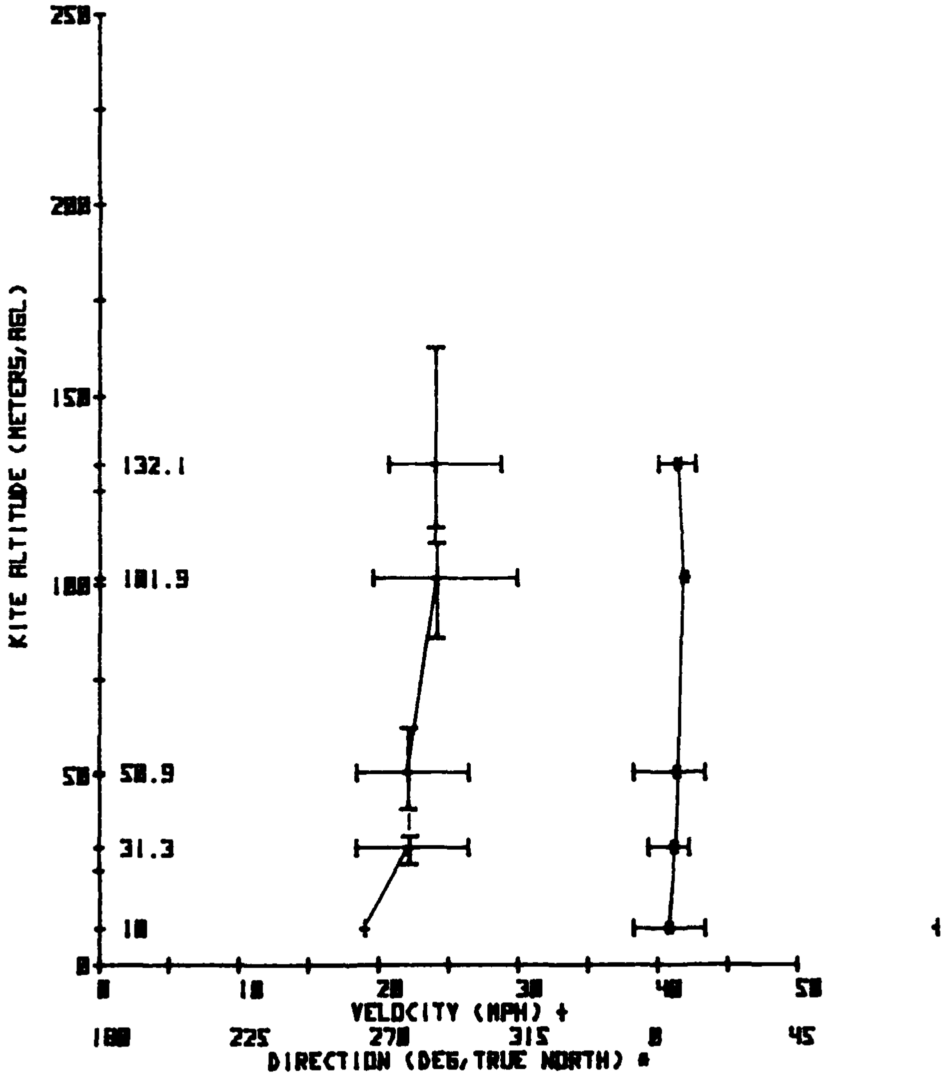



Figure A-50. TALA Record No. 6, Site #2

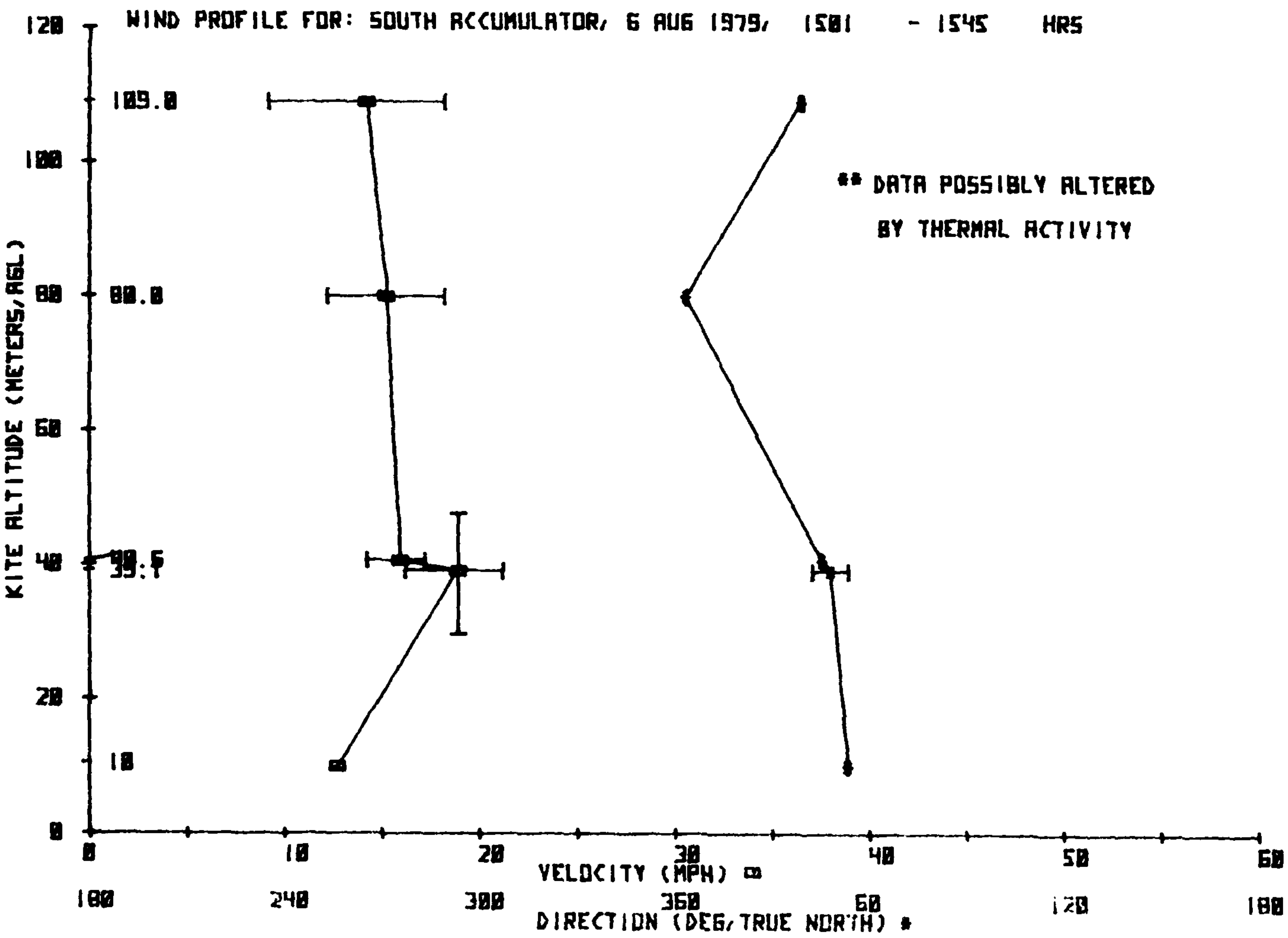



Figure A-51. TALA Record, Site #3

APPENDIX B

DESKTOP COMPUTER PROGRAM LISTINGS

Program CKETAC

Listing

```
10 COM R(45),A$[100],B$[100]
20 DIM S(45),F(45),T(45),C(66),B(11)
[illegible] TO 50
[illegible] THEN 60
[illegible]
[illegible] 45 THEN 90
[illegible]
[illegible]
90 NEXT I
100 F$=""
[illegible]
[illegible] DISP "DATA ON TAPE"
[illegible] INPUT [illegible]$
[illegible] IF Y$="N" THEN 220
[illegible] DISP "WHAT IS FILE NAME"
[illegible] INPUT [illegible]$
[illegible] CLEAR
[illegible] ASSIGN# 1 TO [illegible]$
[illegible] READ# [illegible] A$,B$,F[illegible]
[illegible] ASSIGN# 1 TO [illegible]
[illegible] GOTO 470
[illegible] DISP "DATA LOCATION"
[illegible] INPUT B$
[illegible] DISP "PERIOD OF DATA"
[illegible] INPUT A$
[illegible] DISP "DO YOU ALREADY KNOW [illegible]"
[illegible] INPUT [illegible]$
[illegible] IF [illegible]$="[illegible]" THEN 340
[illegible] DISP "[illegible] IN MPH [illegible]"
[illegible] INPUT [illegible]
[illegible] DISP "[illegible]"
[illegible] INPUT [illegible]
[illegible] GOTO 1540
[illegible] FOR I=0 TO 45
[illegible] DISP "VELOCITY=";I;"OCCURRENCES="
[illegible] INPUT R(I)
[illegible] NEXT I
[illegible] DISP "DO YOU WISH TO [illegible] THIS DATA"
[illegible] INPUT [illegible]$
[illegible] IF [illegible]$="[illegible]" THEN 470
[illegible] DISP "WHAT DO YOU [illegible]"
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] ASSIGN [illegible] TO [illegible]
[illegible] CLEAR
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
```

```
550 INPUT F$
560 IF F$="Y" THEN 600
570 CLEAR
580 DISP "STANDBY*COMPUTATIONS U
    NDERWAY"
590 GOTO 790
600 PRINT "DATA COLLECTED  " B$
610 PRINT "DATA PERIOD, " A$
620 PRINT
630 PRINT
640 PRINT "WIND SPEED OCCURRENCE
    S  %TIME@SP"
650 PRINT "KTS    MPH"
660 IMAGE 3D,2X,3D.D,4X,5D,6X,3D
     D
670 IMAGE 3D,2X,3D.D,4X,5D,8X,D
    D
680 FOR I=0 TO 45
690 IF R(I)/T9*100<1 THEN 700 EL
    SE 720
700 PRINT USING 660 ; I,I*1.152,
    R(I),R(I)/T9*100
710 GOTO 730
720 PRINT USING 670 ; I,I*1.152,
    R(I),R(I)/T9*100
730 NEXT I
740 PRINT
750 PRINT
760 PRINT "WIND SPEED OCCURRENCE
    S  % SPEED"
770 I=0
780 PRINT USING 660 ; I,I,R(I),T
    ,T9*100
790 T(0)=1-R(0)/T9
800 N=R(0)
810 FOR I=1 TO 45
820 N=N+R(I)
830 T(I)=1-N/T9
840 NEXT I
850 IF F$="N" THEN 920
860 FOR I=1 TO 45
870 IF T(I-1)*100<1 THEN 880 ELS
    E 900
880 PRINT USING 660 ; I,I*1.152,
    R(I),T(I-1)*100
890 GOTO 910
900 PRINT USING 670 ; I,I*1.152,
    R(I),T(I-1)*100
910 NEXT I
920 IMAGE 3X,"AVERAGE WIND SPEED
     ",3D.2D,"MPH",3D.2D,"KN
    OTS"
930 PRINT USING 920 ; A/T9,A/(T9
    *1.152)
940 T2=1
950 T3=45
960 DISP
970 D
980 DI
990 DISP "PROGRAM IS PRESENTLY S
    ET UP TO"
```

```
1000 DISP "COMPUTE C AND K FOR V
     ELOCITIES"
1010 DISP "FROM 1 TO 45 KNOTS  I
     F THESE ARE"
1020 DISP "THE LIMITS YOU WISH T
     O USE TYPE"
1030 DISP "IN Y AND PRESS END LI
     NE  IF THEY"
1040 DISP "ARE NOT, TYPE IN N AN
     D PRESS END"
1050 DISP "LINE "
1060 INPUT Y$
1070 IF Y$="Y" THEN 1180
1080 DISP "WHAT VELOCITY DO YOU
     WISH TO "
1090 DISP "START AT (NOTE: YOU C
     AN NOT "
1100 DISP "START AT ZERO!!!)"
1110 INPUT T6
1120 IF T6=0 THEN 1080
1130 DISP "WHAT VELOCITY DO YOU
     WISH TO"
1140 DISP "STOP AT (NOTE: IT MUS
     T BE NO "
1150 DISP "GREATER THAN 45)"
1160 INPUT T8
1170 IF T8>45 THEN 1130
1180 CLEAR
1190 DISP "STAND BY"
1200 T7=T6-1
1210 T7=T7+1
1220 B(1)=LOG(T7*1.152)
1230 IF T7>T8 THEN 1330
1240 IF T(T7)=0 THEN 1330
1250 B(2)=LOG(-LOG(T(T7)))
1260 B(3)=B(3)+B(1)
1270 B(4)=B(4)+B(1)^2
1280 B(5)=B(5)+B(2)
1290 B(6)=B(6)+B(2)^2
1300 B(7)=B(7)+B(1)*B(2)
1310 B(11)=B(11)+1
1320 GOTO 1210
1330 B(8)=SQR((B(4)-B(3)^2/B(11)
     )/(B(11)-1))
1340 B(9)=SQR((B(6)-B(5)^2/B(11)
     )/(B(11)-1))
1350 B(10)=(B(7)-B(3)*B(5)/B(11)
     )/(B(11)-1)/B(8)/B(9)
1360 CLEAR
1370 PRINT
1380 PRINT
1390 PRINT "FOR V=";T6;"TO ";T8;
     "KTS"
1400 PRINT "NUMBER OF POINTS ="
     B(11)
1410 PRINT
1420 PRINT "X   MEAN= " B(3)/B(1
     1)
1430 PRINT "X   STANDARD DEVIATI
     ON= " B(8)
```

```
1440 PRINT
1450 PRINT "Y:  MEAN= ";B(5)/B(
     1)
1460 PRINT "Y:  STANDARD DEVIATI
     ON= ",B(9)
1470 PRINT "CORR  COEFF = ";B(10
     )
1480 A,B,C,D,K=0
1490 D=B(11)*B(4)-B(3)^2
1500 A=(B(5)*B(4)-B(7)*B(3))/D
1510 B=(B(11)*B(7)-B(3)*B(5))/D
1520 C=EXP(-A/B)
1530 K=B
1540 PRINT
1550 PRINT
1560 PRINT "C= ",C,"  K= ";K
1570 GCLEAR
1580 SCALE 0,32,0,16
1590 MOVE 0,15
1600 LDIR 0
1610 LABEL "PLOT OF PERCENT TIME
      AT SPEED VS"
1620 MOVE 0,14
1630 LABEL "WIND SPEED FOR C="&V
     AL$(C)
1640 MOVE 15,12
1650 LABEL "K="&VAL$(K)
1660 MOVE 27,13
1670 LABEL "(MPH)"
1680 MOVE 15,11
1690 LABEL B$
1700 MOVE 15,10
1710 LABEL A$
1720 XAXIS 5,0,10,20
1730 YAXIS 10,0,5,12
1740 MOVE 10,4
1750 LABEL "VELOCITY(MPH)"
1760 MOVE 10,3
1770 LABEL "VELOCITY(KTS)"
1780 MOVE 8,5
1790 LDIR 90
1800 LABEL "% TIME"
1810 MOVE 9,5
1820 LABEL "@ SPD"
1830 PRINT
1840 PRINT
1850 PRINT
1860 COPY
1870 GCLEAR
1880 SCALE -4,38,-8,21
1890 XAXIS 0,1,0,35
1900 YAXIS -3.5,1.152,0,35
1910 LDIR 0
1920 FOR X=0 TO 5 STEP 5
1930 MOVE X,1.5
1940 IDRAW 0,-2
1950 MOVE X-.5,-2.5
1960 LABEL VAL$(X)
1970 MOVE X*1.152-.5,-6
1980 LABEL VAL$(X)
```

```
1990 NEXT X
2000 FOR X=10 TO 35 STEP 5
2010 MOVE X,1.5
2020 IDRAW 0,-2
2030 MOVE X-1,-2.5
2040 LABEL VAL$(X)
2050 MOVE X*1.152-1,-6
2060 IF X>33 THEN 2080
2070 LABEL VAL$(Y)
2080 NEXT X
2090 YAXIS 0,1,1,20
2100 LDIR 0
2110 FOR Y=0 TO 20 STEP 5
2120 MOVE 0,Y
2130 IDRAW 1,0
2140 MOVE -3,Y-.5
2150 LABEL VAL$(Y)
2160 NEXT Y
2170 IF W$="Y" THEN 2260
2180 FOR I=0 TO 30
2190 Y=R(I)/T9*100
2200 X=I*1.152
2210 MOVE X,Y
2220 IMOVE -.2,.2
2230 IDRAW .75,0 @ IDRAW 0,-.75
2240 IDRAW -.75,0 @ IDRAW 0,.75
2250 NEXT I
2260 MOVE 0,0
2270 FOR I=1 TO 30
2280 X=I*1.152
2290 Y=100*(EXP(-((X-.576)/C)^K)
     -EXP(-((X+.576)/C)^K))
2300 DRAW X,Y
2310 NEXT I
2320 MOVE 0,0
2330 PRINT
2340 PRINT
2350 PRINT
2360 COPY
2370 PRINT
2380 PRINT
2390 PRINT
2400 GCLEAR
2410 SCALE 0,32,0,16
2420 MOVE 0,15
2430 LDIR 0
2440 LABEL "PLOT OF PERCENT HOUR
     S ABOVE      "
2450 MOVE 0,14
2460 LABEL "SPEED FOR C="&VAL$(C
     )
2470 MOVE 27,14
2480 LABEL "MPH"
2490 MOVE 15,13
2500 LABEL "K="&VAL$(K)
2510 MOVE 15,12
2520 LABEL B$
2530 MOVE 15,11
2540 LABEL A$
2550 XAXIS 5,0,10,20
```

```
2560 YAXIS 10,0,5,12
2570 MOVE 10,4
2580 LABEL "%TIME"
2590 MOVE 10,3
2600 LABEL "ABOVE SPD"
2610 MOVE 8,5
2620 LDIR 90
2630 LABEL "VEL (KTS)"
2640 MOVE 9,5
2650 LABEL "VEL (MPH)"
2660 LDIR 0
2670 PRINT
2680 PRINT
2690 PRINT
2700 COPY
2710 GCLEAR
2720 SCALE -20,105,-4,38
2730 XAXIS 0,10,0,100
2740 X=0
2750 MOVE X-1,-2.5
2760 LABEL VAL$(X)
2770 FOR X=20 TO 80 STEP 20
2780 MOVE X-3,-2.5
2790 LABEL VAL$(X)
2800 NEXT X
2810 X=100
2820 MOVE X-4.5,-2.5
2830 LABEL VAL$(X)
2840 YAXIS 0,5,0,35
2850 YAXIS -10,5*1.152,0,35
2860 FOR Y=0 TO 35 STEP 5
2870 MOVE -8,Y-1
2880 LABEL VAL$(Y)
2890 IF Y=35 THEN 2920
2900 MOVE -18,Y*1.152-1
2910 LABEL VAL$(Y)
2920 NEXT Y
2930 IF W$="Y" THEN 3000
2940 FOR Y=35 TO 1 STEP -1
2950 MOVE T(Y-1)*100,Y
2960 IMOVE -.2,.2
2970 IDRAW .75,0 @ IDRAW 0,-.75
2980 IDRAW -.75,0 @ IDRAW 0,.75
2990 NEXT Y
3000 MOVE 0,35
3010 FOR X=1 TO 100
3020 Y=C*(-LOG(X/100))^(1/F)
3030 DRAW X,Y
     NEXT X
     PRINT
     PRINT
     PRINT
     COPY
3090 PRINT
3100 PRINT
3110 PRINT
3120 END
```

Program CKCOMP

**Listing**

```
5 ! PROGRAM "CKCOMP"
10 ... D(32,8),A$[30] ...

20 ... S(...),P(32),T(32),C(60)
   B(11)
30 J=0
40 FOR I=0 TO 66
   J=J+1
   IF I>11 THEN 80
70 B(I)=0
80 IF I>32 THEN 110
90 S(I),P(I),T(I),R(I)=0
100 IF J<9 THEN D(I,J)=0
110 C(I)=0
120 NEXT I
    F$="Y"
140 W$="N"
    DISP "DATA ON TAPE"
160 INPUT Y$
    IF Y$="N" THEN 430
    DISP "WHAT IS FILE CALLED"
    INPUT U$
    CLEAR
210 ASSIGN# 1 TO U$
220 READ# 1,1 ; A$,B$,D(,)
230 ASSIGN# 1 TO *
240 FOR I=1 TO 32
250 FOR J=1 TO 8
260 R(I)=R(I)+D(I,J)
270 NEXT J
280 NEXT I
290 DISP "DO YOU WISH TO SEE DATA
    "
300 INPUT Y$
310 IF Y$="N" THEN 1340
320 DISP "DO YOU WANT PRINTED CO
    PY OF DATA"
330 INPUT C$
340 CLEAR
350 FOR I=1 TO 32
360 GOSUB 790
370 DISP USING 1170 ; R(I)
380 DISP
    DISP
400 IF C$="Y" THEN COPY ELSE WAI
    T 4000
410 NEXT I
420 GOTO 1340
    DISP "WILL YOU NEED PRINTED
    COPY OF   THIS DATA"
440 INPUT C$
450 DISP "... LOCATION";
    INPUT E$
    DISP "PERIOD OF DATA";
480 INPUT A$
490 DISP "DO YOU ALREADY KNOW C
    AND ..."
500 INPUT W$
510 IF W$="N" THEN 570
520 DISP "C ... =";
```

```
530 INPUT
540 DISP "V ="
550 INPUT V
560 GOTO 2400
570 FOR I=1 TO 32
580 IMAGE " OCCURRENCES  BETWEEN "
    DD." AND " DD." MPHFROM THE
    ",AA
590 DISP USING 580 , 2*I-2,2*I,"
    SE"
600 INPUT D(I,1)
610 DISP USING 580 , 2*I-2,2*I,"
    E"
620 INPUT D(I,2)
630 DISP USING 580 , 2*I-2,2*I,"
    NE"
640 INPUT D(I,3)
650 DISP USING 580 , 2*I-2,2*I,"
    N"
660 INPUT D(I,4)
670 DISP USING 580 , 2*I-2,2*I,"
    NW"
680 INPUT D(I,5)
690 DISP USING 580 , 2*I-2,2*I,"
    W"
700 INPUT D(I,6)
710 DISP USING 580 , 2*I-2,2*I,"
    SW"
720 INPUT D(I,7)
730 DISP USING 580 , 2*I-2,2*I,"
    S"
740 INPUT D(I,8)
750 CLEAR
760 GOSUB 780
770 GOTO 950
780 DISP
790 DISP
800 IMAGE "FOR VELOCITIES FROM "
     DD." TO "DD." MPH"
810 DISP USING 800 , 2*I-2,2*I
820 IMAGE 4X,"DIRECTION",5X,"OCC
    URANCES",4X
830 IMAGE 7X,AA,10X,7D,X
840 DISP
    DISP USING 820
    DISP USING 830 , "SE",D(I,1)
870 DISP USING 830 , " E",D(I,2)
880 DISP USING 830 , "NE",D(I,3)
890 DISP USING 830 , " N",D(I,4)
900 DISP USING 830 , "NW",D(I,5)
910 DISP USING 830 , " W",D(I,6)
920 DISP USING 830 , "SW",D(I,7)
930 DISP USING 830 , " S",D(I,8)
940 RETURN
950 DISP "IS ALL DATA CORRECT",
960 INPUT Y$
970 IF Y$="Y" THEN 1120
980 BEEP
990 CLEAR
1000 DISP "INPUT NUMBER CORRESPO
     NDING TO   INCORRECT DIRECT
     ION"
```

```
1010 IMAGE 8X,AAAA,8X,AAAA,7X
1020 DISP USING 1010 ; "SE=1","N
     W=5"
1030 DISP USING 1010 ; " E=2","
     W=6"
1040 DISP USING 1010 ; "NE=3","S
     W=7"
1050 DISP USING 1010 ; " N=4","
     S=8"
1060 INPUT J
1070 DISP "CORRECT NUMBER OF OCC
     URRENCES"
1080 INPUT D(I,J)
1090 DISP "ANY OTHERS WRONG"
1100 INPUT Y$
1110 IF Y$="Y" THEN 990
1120 CLEAR
1130 FOR J=1 TO 8
1140 R(I)=R(I)+D(I,J)
1150 NEXT J
1160 GOSUB 780
1170 IMAGE 5X,"TOTAL = ",7D
1180 DISP USING 1170 ; R(I)
1190 IF C$="Y" THEN COPY ELSE WA
     IT 2000
1200 CLEAR
1210 NEXT I
1220 DISP "DO YOU WISH TO STORE
     THIS DATA",
1230 INPUT Y$
1240 IF Y$="N" THEN 1340
1250 DISP "WHAT DO YOU WISH TO C
     ALL FILE",
1260 INPUT U$
1270 CLEAR
1280 CREATE U$,1,2560
1290 ASSIGN# 1 TO U$
1300 PRINT# 1,1 ; A$,B$,D(,)
1310 ASSIGN# 1 TO *
1340 A=0
1350 T9=0
1360 FOR I=1 TO 32
1370 T9=T9+R(I)
1380 A=A+(I*2-1)*R(I)
1390 NEXT I
1400 DISP "DO YOU WANT PERCENTAG
     ES LISTED",
1410 INPUT F$
1420 IF F$="Y" THEN 1460
1430 CLEAR
1440 DISP "STANDBY*COMPUTATIONS
     UNDERWAY"
1450 GOTO 1650
1460 CLEAR
1465 PRINT "DATA COLLECTED, ",B$

1470 PRINT "DATA PERIOD, ",A$
1480 PRINT
1490 PRINT
1500 PRINT "WIND SPEED OCCURRENC
     ES  %TIME@SP"
```

```
1510 PRINT "    MPH      "
1520 IMAGE 3D,2X,3D,4X,8D,6X,3D
     D
1530 IMAGE 3D,2X,3D,4X,8D,8X,Z D
1540 FOR I=1 TO 32
1550 IF R(I)/T9*100>1 THEN 1560
     ELSE 1590
1560 PRINT USING 1520 ; 2*I-2,2*
     I,R(I),R(I)/T9*100
1570 GOTO 1590
1580 PRINT USING 1530 ; 2*I-2,2*
     I,R(I),R(I)/T9*100
1590 NEXT I
1600 PRINT
1610 PRINT
1620 PRINT "WIND SPEED OCCURRENC
     ES  %>SPEED"
1630 I=1
1640 PRINT USING 1520 ; 0,2,R(I)
     ,T9/T9*100
1650 T(1)=1-R(1)/T9
1660 N=R(1)
1670 FOR I=2 TO 32
1680 N=N+R(I)
1690 T(I)=1-N/T9
1700 NEXT I
1710 IF F$="N" THEN 1790
1720 FOR I=2 TO 32
1730 IF T(I-1)*100>1 THEN 1740 E
     LSE 1760
1740 PRINT USING 1520 ; 2*I-2,2*
     I,R(I),T(I-1)*100
1750 GOTO 1770
1760 PRINT USING 1530 ; 2*I-2,2*
     I,R(I),T(I-1)*100
1770 NEXT I
1780 IMAGE 3/,"AVERAGE WIND SPEE
     D ",/,3D.2D,"MPH",/,3D.2D,"
     KNOTS"
1790 PRINT USING 1780 ; A/T9,A/(
     T9*1.152)
1800 T6=8
1810 T8=32
1820 DISP
1830 DISP
1840 DISP
1850 DISP "PROGRAM IS PRESENTLY
     SET UP TO"
1860 DISP "COMPUTE C AND K FOR V
     ELOCITIES"
1870 DISP "FROM 15 TO 63 MPH  IF
      THESE ARE "
1880 DISP "THE LIMITS YOU WISH T
     O USE TYPE"
1890 DISP "IN Y AND PRESS END LI
     NE  IF THEY"
1900 DISP "ARE NOT, TYPE IN N AN
     D PRESS END"
1910 DISP "LINE "
1920 INPUT Y$
```

```
1930 IF ,$="Y" THEN 2040
1940 DISP "WHAT VELOCITY DO YOU
     WISH TO "
1950 DISP "START AT (NOTE  YOU C
     AN NOT "
1960 DISP "START AT ZERO!!! AND
     NUMBER MUSTBE AN ODD  WHOLE
      NUMBER)    "
1970 INPUT T6
1980 IF T6=0 THEN 1940
1985 T6=(T6+1)/2
1990 DISP "WHAT VELOCITY DO YOU
     WISH TO"
2000 DISP "STOP AT (NOTE) IT MUS
     T BE NO "
2010 DISP "GREATER THAN 63 AND M
     UST BE AN   "
2015 DISP "ODD, WHOLE NUMBER)"
2020 INPUT T8
2030 IF T8>63 THEN 1990
2035 T8=(T8+1)/2
2040 CLEAR
2050 DISP "STAND BY"
2060 T7=T6-1
2070 T7=T7+1
2080 B(1)=LOG(2*T7-1)
2090 IF T7>T8 THEN 2190
2100 IF T(T7)=0 THEN 2190
2110 B(2)=LOG(-LOG(T(T7)))
2120 B(3)=B(3)+B(1)
2130 B(4)=B(4)+B(1)^2
2140 B(5)=B(5)+B(2)
2150 B(6)=B(6)+B(2)^2
2160 B(7)=B(7)+B(1)*B(2)
2170 B(11)=B(11)+1
2180 GOTO 2070
2190 B(8)=SQR((B(4)-B(3)^2/B(11
     ))/(B(11)-1))
2200 B(9)=SQR((B(6)-B(5)^2/B(11
     ))/(B(11)-1))
2210 B(10)=(B(7)-B(3)*B(5)/B(11
     ))/(B(11)-1)/B(8)/B(9)
2220 CLEAR
2230 PRINT
2240 PRINT
2250 PRINT "FOR V=";T6*2-1,"TO "
     ,T8*2-1," MPH"
2260 PRINT "NUMBER OF POINTS ="
     B(11)
2270 PRINT
2280 PRINT "X   MEAN= ",B(3)/B(1
     1)
2290 PRINT "X   STANDARD DEVIATI
     ON= ",B(8)
2300 PRINT
2310 PRINT "Y   MEAN= ",B(5)/B(1
     1)
2320 PRINT "Y   STANDARD DEVIATI
     ON= ",B(9)
2330 PRINT "CORR  COEFF = ",B(10
     )
```

```
2240 A=0 D,K=0
2250 C=F(11)*B(4)-B(3)^2
2260 A=(B(5)*B(4)-B(7)*B(3))/D
2270 E=(B(11)*B(7)-B(3)*B(5))/D
2280 C=EXP(-A/B)
2290 K=B
2400 PRINT
2410 PRINT
2420 PRINT "C= ";C;"   K= ";K
2430 GCLEAR
2440 SCALE 0,32,0,16
2450 MOVE 0,15
2460 LDIR 0
2470 LABEL "PLOT OF PERCENT TIME
      AT SPEED VS"
2480 MOVE 0,14
2490 LABEL "WIND SPEED FOR C="&V
      AL$(C)
2500 MOVE 15,12
2510 LABEL "K="&VAL$(K)
2520 MOVE 27,13
2530 LABEL "(MPH)"
2540 MOVE 15,11
2550 LABEL B$
2560 MOVE 15,10
2570 LABEL A$
2580 XAXIS 5,0,10,20
2590 YAXIS 10,0,5,12
2600 MOVE 10,4
2610 LABEL "VELOCITY(MPH)"
2640 MOVE 8,5
2650 LDIR 90
2660 LABEL "% TIME"
2670 MOVE 9,5
2680 LABEL "@ SPD"
2690 PRINT
2700 PRINT
2710 PRINT
2720 COPY
2730 GCLEAR
2740 SCALE -4,78,-4,21
2750 XAXIS 0,1,0,35
2760 LDIR 0
2770 FOR X=0 TO 5 STEP 5
2780 MOVE X,1.5
2790 IDRAW 0,-2
2800 MOVE X-.5,-2.5
2810 LABEL VAL$(X)
2820 NEXT X
2860 FOR X=10 TO 35 STEP 5
2870 MOVE X,1.5
2880 IDRAW 0,-2
2890 MOVE X-1,-2.5
2900 LABEL VAL$(X)
2940 NEXT
2900 YAXIS 0,1,1,20
2960 LDIR 0
2970 FOR Y=0 TO 20 STEP 5
2980 MOVE 0,Y
2990 IDRAW 1,0
```

```
3000 MOVE -3,Y-.5
3010 LABEL VAL$(Y)
3020 NEXT Y
3030 IF W$="Y" THEN 3120
3040 FOR I=1 TO 18
3050 Y=R(I)/T9*100
3060 X=I*2-1
3070 MOVE X,Y
3080 IMOVE -.2,.2
3090 IDRAW .75,0 @ IDRAW 0,-.75
3100 IDRAW -.75,0 @ IDRAW 0,.75
3110 NEXT I
3120 MOVE 0,0
3130 FOR I=1 TO 35
3140 X=I
3150 Y=100*(EXP(-((X-1)/C)^K)-EX
     P(-((X+1)/C)^K))
3160 DRAW X,Y
3170 NEXT I
3180 MOVE 0,0
3190 PRINT
3200 PRINT
3210 PRINT
3220 COPY
3230 PRINT
3240 PRINT
3250 PRINT
3260 GCLEAR
3270 SCALE 0,32,0,16
3280 MOVE 0,15
3290 LDIR 0
3300 LABEL "PLOT OF PERCENT HOUR
     S ABOVE     "
3310 MOVE 0,14
3320 LABEL "SPEED FOR C="&VAL$(C
     )
3330 MOVE 27,14
3340 LABEL "MPH"
3350 MOVE 15,13
3360 LABEL "K="&VAL$(K)
3370 MOVE 15,12
3380 LABEL B$
3390 MOVE 15,11
3400 LABEL A$
3410 XAXIS 5,0,10,20
3420 YAXIS 10,0,5,12
3430 MOVE 10,4
3440 LABEL "%TIME"
3450 MOVE 10,3
3460 LABEL "ABOVE SPD"
3480 LDIR 90
3500 MOVE 9,5
3510 LABEL "VEL (MPH)"
3520 LDIR 0
3530 PRINT
3540 PRINT
3550 PRINT
3560 COPY
3570 GCLEAR
3580 SCALE -10,105,-4,38
```

```
3590 XAXIS 0,10,0,100
3600 X=0
3610 MOVE X-1,-2.5
3620 LABEL VAL$(X)
3630 FOR X=20 TO 80 STEP 20
3640 MOVE X-3,-2.5
3650 LABEL VAL$(X)
3660 NEXT X
3670 X=100
3680 MOVE X-4.5,-2.5
3690 LABEL VAL$(X)
3700 YAXIS 0,5,0,35
3720 FOR Y=0 TO 35 STEP 5
3730 MOVE -8,Y-1
3740 LABEL VAL$(Y)
3780 NEXT Y
3790 IF W$="Y" THEN 3860
3800 FOR Y=18 TO 1 STEP -1
3810 MOVE T(Y-1)*100,Y*2-1
3820 IMOVE -.2,.2
3830 IDRAW .75,0 @ IDRAW 0,-.75
3840 IDRAW -.75,0 @ IDRAW 0,.75
3850 NEXT Y
3860 MOVE 0,35
3870 FOR X=1 TO 100
3880 Y=C*(-LOG(X/100))^(1/K)
3890 DRAW X,Y
3900 NEXT X
3910 PRINT
3920 PRINT
3930 PRINT
3940 COPY
3950 PRINT
3960 PRINT
3970 PRINT
3990 END
```

Program WEIPOW

Listing

```
10 P1,P2,P3,C,K=0
20 CLEAR
30 DISP "THIS PROGRAM COMPUTES
   WATTS PER"
40 DISP "SQUARE METER GIVEN A V
   ALUE FOR"
50 DISP " C IN MILES PER HOUR A
   ND A K (NO"
60 DISP "UNITS)"
70 DISP
80 DISP
90 DISP "**WHAT IS YOUR VALUE F
   OR C**";
100 INPUT C
110 DISP "**WHAT IS YOUR VALUE F
   OR K**";
120 INPUT K
130 CLEAR
140 DISP "STANDBY*COMPUTATIONS I
   N PROGRESS"
150 FOR I=1 TO 45
160 P1=EXP(-((I-.576)/C)^K)-EXP(
   -((I+.576)/C)^K)
170 P2=23.05*.001928*I^3*P1
180 P3=P3+P2
190 NEXT I
200 CLEAR
210 DISP " C=";C;"MPH"
220 DISP " K=";K
230 IMAGE "WEIBULL POWER = " 4D
   DD,"(W/M^2)"
240 DISP USING 230 ; P3
250 DISP "DO YOU WANT PRINTED CO
   PY";
260 INPUT Y$
270 IF Y$="N" THEN 310
280 PRINT " C= ";C;"MPH"
290 PRINT " K= ";K
300 PRINT USING 230 ; P3
310 DISP "DO YOU WANT TO COMPUTE
    POWER FOR"
320 DISP "OTHER C's AND K's"
330 INPUT Y$
340 IF Y$="Y" THEN 10
350 END
```

Program CHGHGT

Listing

```
10  C1,C2,K1,K2,Z1,Z2,N1,D1,N,N2
    ,D2=0
20  DISP "HEIGHT (IN METERS) FOR
     WHICH C  AND K WERE ORIGINA
    LLY COMPUTED";
30  INPUT Z1
40  IMAGE "C IN METERS PER SEC     F
    OR " DDD." M       HEIGHT"
50  DISP USING 40 ; Z1
60  INPUT C1
70  IMAGE "K FOR ",DDD,"METER HE
    IGHT",
80  DISP USING 70 ; Z1
90  INPUT K1
100 DISP "NEW HEIGHT AT WHICH YO
    U WANT C  AND K COMPUTED";
110 INPUT Z2
120 N1=.37-.088*LOG(C1)
130 D1=1-.088*LOG(Z1/10)
140 N=N1/D1
150 N2=1-.088*LOG(Z1/10)
160 D2=1-.088*LOG(Z2/10)
170 K2=K1*(N2/D2)
180 C2=C1*(Z2/Z1)^N
190 IMAGE "OLD HEIGHT",17X,DDD,"
     M"
200 IMAGE "NEW HEIGHT",17X,DDD,"
     M"
210 IMAGE "OLD C",13X,DD.DDDDDDD
        MPH"
220 IMAGE "NEW C",13X,DD.DDDDDDD
    ," MPH"
230 IMAGE "OLD K",17X,DD.DDDDDDD
240 IMAGE "NEW K",17X,DD.DDDDDDD
245 CLEAR
250 PRINT
260 PRINT
270 PRINT USING 190
280 PRINT USING 210
290 PRINT USING 230
300 PRINT
310 PRINT
    PRINT USING 200 ; Z2
    PRINT USING 220 ; C2
    PRINT USING 240 ; K2
    PRINT
    PRINT
```

## Program WINDE1

### Listing

```
10  DISP "***CHECK UNITS-THIS PR
    OGRAM SET"
20  DISP "UP FOR ENGLISH UNITS"
30  DISP
40  DISP
50  DISP "NAME OF WIND MACHINE U
    NDER CON- "
60  DISP "SIDERATION"
70  INPUT A$
80  DISP "WHAT IS THE CUT-IN VEL
    OCITY OF  "
90  DISP "THE WIND MACHINE (IN M
    PH)"
100 INPUT V1
110 DISP "WHAT IS ITS RATED VELO
    CITY (MPH)"
120 INPUT V2
130 DISP "WHAT IS THE CUT-OUT VE
    LOCITY      "
140 DISP "(MPH)"
150 INPUT V3
160 DISP "HOW MANY 1 MPH INTERVA
    LS BETWEEN"
170 DISP "THE CUT-IN VELOCITY AN
    D THE       "
180 DISP "RATED VELOCITY"
190 INPUT N
200 DISP "WHAT IS THE TURBINE RA
    TED POWER "
210 DISP "(KW)"
220 INPUT R
230 DISP "WHAT IS THE TURBINE RO
    TOR         "
240 DISP "DIAMETER (FEET)"
250 INPUT R2
260 A1=PI*R2^2/4
270 DISP "WHERE IS WINDMILL TO B
    E LOCATED"
280 INPUT B$
290 DISP "HOW HIGH IS THIS SITE
    ABOVE SEA "
300 DISP "LEVEL (IN FEET)"
310 INPUT A2
320 DISP "WHAT IS WEIBULL CONSTA
    NT C IN    "
330 DISP "MPH FOR THIS LOCATION"
340 INPUT C
350 DISP "WHAT IS WEIBULL CONSTA
    NT K FOR   "
360 DISP "THIS LOCATION"
370 INPUT K
380 DISP "FOR HOW MANY HOURS WIL
    L POWER BE"
390 DISP "GENERATED"
400 INPUT H
410 DISP "HOW MUCH DOES COMMERC
    IAL ELEC- "
420 DISP "TRICITY COST ($/KW-HR)
    "
430 INPUT C8
```

```
440 CLEAR
450 DISP "STAND-BY"
460 A3=-2 615714285715E-5*A2+ 995
    952380953
470 C2= 698862313252+ 5152599931
    22*K- 200065665166*K^2+2 500
    33443925E-2*K^3
480 V6=C/C2
490 V7=V6^3
500 V8=12 7994920987-11 99684103
    83*K+4 34094645567*K^2- 5357
    50633732*K^3
510 V9=V8*V7
520 S=(V2-V1)/N
530 V4=(V1+V2)/2
540 D=(V2-V1)*(V4^2-V1^2)-(V4-V1
    )*(V2^2-V1^2
550 B=(V4^2-V1^2-(V4/V2)^3*(V2^2
    -V1^2))/D
560 C1=((V4/V2)^3*(V2-V1)-(V4-V1
    ))/D
570 A=-B*V1-C1*V1^2
580 P=A
590 V5=V1+S/2
600 FOR I=1 TO N
610 P=P+(A+B*V5+C1*V5^2)*(EXP(-(
    (V5-S/2)/C)^K)-EXP(-((V5+S/2
    )/C)^K))*S
620 V5=V5+S
630 NEXT I
640 P1=P
650 P2=P1*P
660 P3=P1*(EXP(-(V2/C)^K)-EXP(-(
    [illegible]
670 P[illegible] P3
680 P[illegible] P
690 [illegible] P4
700 P = 0000051*A3*A1*V9
710 P8=P4/P7
720 D1=P6/((R2/2* 3048)^2*PI)*C9
730 IMAGE "THIS DATA IS FOR A"
740 IMAGE 20A,2X,"WINDMILL"
750 CLEAR
760 PRINT USING 730
770 PRINT USING 740 ; A$
780 IMAGE "SITED AT",2X 20A
790 PRINT USING 780 ; B$
800 PRINT
810 PRINT
820 PRINT
830 IMAGE "******WINDMILL INFORM
    ATION******"
840 PRINT USING 830
850 IMAGE "CUT-IN VELOCITY",8X,
    DDD D " MPH"
860 PRINT USING 850 ; V1
870 IMAGE "RATED VELOCITY",9X,DD
    D D," MPH"
880 PRINT USING 870 ; V2
890 IMAGE "1 MPH INTERVALS",15X,
    DD
```

```
900 PRINT USING 890 : N
910 IMAGE "CUT-OUT VELOCITY",7X,
    DDD.D," MPH"
920 PRINT USING 910 : V3
930 IMAGE "TURBINE DIAMETER",5X,
    DDDD.D," FEET"
940 IMAGE "SWEPT AREA",8X,DDDDDD
    .D," SQ FT"
950 PRINT USING 930 : R2
960 PRINT USING 940 : A1
970 IMAGE "RATED POWER",12X,DDDD
    .D," KW"
980 PRINT USING 970 : R
990 PRINT
1000 PRINT
1010 IMAGE "********SITE INFORMA
     TION********"
1020 PRINT USING 1010
1030 IMAGE "SITE ELEVATION",8X,D
     DDDD," FEET"
1040 PRINT USING 1030 : A2
1050 IMAGE "C",18X,DD.DDDDDD," M
     PH"
1060 PRINT USING 1050 : C
1070 IMAGE "K",23X,DD.DDDDDD
1080 PRINT USING 1070 : K
1090 IMAGE "AVERAGE WINDSPEED",5
     X,DDD.DD," MPH"
1100 PRINT USING 1090 : V6
1110 PRINT
1120 PRINT
1130 IMAGE "********POWER INFORM
     ATION*******"
1140 PRINT USING 1130
1150 IMAGE "OPERATING TIME",7X,D
     DDDD," HOURS"
1160 PRINT USING 1150 : H
1170 IMAGE "AVE POWER OUTPUT",5X
     ,DDDD.DD," KW"
1180 PRINT USING 1170 : P4
1190 IMAGE "CAPACITY FACTOR",8X,
     D.DDDDDDD
1200 PRINT USING 1190 : P5
1210 IMAGE "ENERGY OUTPUT",4X,DD
     DDDDDDD," KW-HR"
1220 PRINT USING 1210 : P6
1230 IMAGE "RECOVERY FACTOR",8X,
     D.DDDDDDD
1240 PRINT USING 1230 : C
1250 IMAGE "COST OF ENERGY",6X,"
     $",D.DDD,"/KW-HR"
1260 PRINT USING 1250 : C9
1270 IMAGE "UNIT SAVINGS",9X,"$"
     ,DDD.DD," M^2"
1280 PRINT USING 1270: D2
1290 END
```

# Program WINDE2

## Listing

```
10 DISP "***CHECK UNITS- THIS PR
   OGRAM SET"
20 DISP "UP FOR ENGLISH UNITS"
30 DISP
40 DISP
50 DISP "NAME OF WIND MACHINE U
   NDER CON- "
60 DISP "SIDERATION"
70 INPUT A$
80 DISP "WHAT IS THE CUT-IN VEL
   OCITY OF  "
90 DISP "THE WIND MACHINE (IN M
   PH)"
100 INPUT V1
110 DISP "WHAT IS THE CUT-OUT VE
    LOCITY     "
120 DISP "(MPH)"
130 INPUT V3
140 DISP "HOW MANY INTEGRATION S
    TEPS (EVENNUMBER OF 1MPH INT
    ERVALS) BE-      "
150 DISP "TWEEN CUT-IN AND CUT-O
    UT VELOCI-TIES";
160 INPUT N
170 DISP "WHAT IS THE TURBINE RA
    TED POWER "
180 DISP "(KW)"
190 INPUT P
200 DISP "HOW MANY POLYNOMIAL CO
    EFFICIENTSDESCRIBE THE WIND
    TURBINE POWER "
210 DISP "CURVE"
220 INPUT N9
230 IMAGE "MODEL CURVE: Y=A(",DD
    ")X^",DD,"+   A(1)X+A(0)"
240 DISP USING 230 ; N9-1,N9-1
250 FOR I=N9 TO 1 STEP -1
260 K=I-1
270 DISP "INPUT A(";K;")";
280 INPUT A(I)
290 NEXT I
300 DISP "WHAT IS THE TURBINE RO
    TOR        "
310 DISP "DIAMETER (FEET)"
320 INPUT D
330 A=PI*D^2/4
340 DISP "WHERE IS WINDMILL TO B
    E LOCATED"
350 INPUT B$
360 DISP "HOW HIGH IS THIS SITE
    ABOVE SEA "
370 DISP "LEVEL (IN FEET)"
380 INPUT E
390 DISP "WHAT IS WEIBULL CONSTA
    NT C IN    "
400 DISP "MPH FOR THIS LOCATION"
410 INPUT C
420 DISP "WHAT IS WEIBULL CONSTA
    NT K FOR   "
430 DISP "THIS  LOCATION"
```

```
440 INPUT K1
450 DISP "FOR HOW MANY HOURS WIL
    L POWER BE"
460 DISP "GENERATED"
470 INPUT H1
480 DISP "HOW MUCH DOES COMMERC
    IAL ELEC- "
490 DISP "TRICITY COST ($/KW-HR)
    "
500 INPUT C9
510 CLEAR
520 DISP "STAND-BY"
530 Y=.99592380957-2.61571428571
    E-5*E
540 C1=.698862313252+.5152599931
    22*K1-.200065665166*K1^2+2.5
    0023443925E-2*K1^3
550 A1=C/C1
560 V7=A1^3
570 V8=12.7994920987-11.99684103
    83*K1+4.34094645567*K1^2-.53
    5250633732*K1^3
580 V9=V8*V7
590 A2=A*V9*.0000051*Y
600 H=(V3-V1)/N
610 N1=N-1
620 P5=0
630 FOR I=1 TO N1 STEP 2
640 P2=0
650 P3=0
660 P4=0
670 V=0
680 FOR J=1 TO 3
690 IF J=1 THEN 710
700 GOTO 730
710 V=V1+(I-1)*H
720 GOTO 780
730 IF J=2 THEN 750
740 GOTO 770
750 V=V1+I*H
760 GOTO 780
770 V=V1+(I+1)*H
780 P1=0
790 FOR K=1 TO N9
800 P2=A(K)*V^(K-1)
810 P1=P1+P2
820 NEXT K
830 P3=EXP(-((V-H/2)/C)^K1)-EXP(
    -((V+H/2)/C)^K1)
840 P4=P1*P3
850 IF J=2 THEN 870
860 GOTO 880
870 P4=4*P4
880 P5=P5+P4
890 NEXT J
900 NEXT I
910 P6=P5*H/3
920 D1=D*.3049
930 A3=PI*D1^2/4
940 F1=P6/R
```

```
950 F2=P6 A2
960 T2=P6*H1
970 T3=T2/A3
980 T4=C9*T3
990 IMAGE "THIS DATA IS FOR A"
1000 IMAGE 20A,2X,"WINDMILL"
1010 CLEAR
1020 PRINT USING 990
1030 PRINT USING 1000 ; A$
1040 IMAGE "SITED AT",2X,20A
1050 PRINT USING 1040 ; B$
1060 PRINT
1070 PRINT
1080 PRINT
1090 IMAGE "******WINDMILL INFOR
     MATION******"
1100 PRINT USING 1090
1110 IMAGE "CUT-IN VELOCITY",8X,
     DDD.D," MPH"
1120 PRINT USING 1110 ; V1
1130 IMAGE "CUT-OUT VELOCITY",7X
     ,DDD.D," MPH"
1140 PRINT USING 1130 ; V3
1150 IMAGE "INTEGRATION STEPS",1
     2X,DDD
1160 PRINT USING 1150 ; N
1170 IMAGE "TURBINE DIAMETER",5X
     ,DDDD.D," FEET"
1180 PRINT USING 1170 ; D
1190 IMAGE "SWEPT AREA",8X,DDDDD
     D.D," SQ FT"
1200 PRINT USING 1190 ; A
1210 IMAGE "RATED POWER",12X,DDD
     D.D," KW"
1220 PRINT USING 1210 ; R
1230 PRINT
1240 IMAGE "********CURVE INFORM
     ATION********"
1250 PRINT USING 1240
1260 IMAGE "NO  POLY COEFF",16X,
     DD
1270 PRINT USING 1260 ; N9
1280 IMAGE "COEFFICIENTS "
1290 PRINT USING 1280
1300 IMAGE 8X, "A(",DD,")=",SD.D
     DDDDDDDDDE
1310 FOR I=N9 TO 1 STEP -1
1320 PRINT USING 1300 ; I-1,A(I)
1330 NEXT I
1340 PRINT
1350 PRINT
1360 IMAGE "********SITE IMFORMA
     TION*********"
1370 PRINT USING 1360
1380 IMAGE "SITE ELEVATION",8X,D
     DDDD," FEET"
1390 PRINT USING 1380 ; E
1400 IMAGE "C" 18X,DD.DDDDDD," M
     PH"
1410  PRINT USING 1400; C
```

```
1420 IMAGE "K" 22X.DD DDDDDD
1430 PRINT USING 1420 ; K1
1440 IMAGE "AVERAGE WINDSPEED",5
     X.DDD.DD," MPH"
1450 PRINT USING 1440 ; A1
1460 PRINT
1470 PRINT
1480 IMAGE "********POWER INFORM
     ATION*******"
1490 PRINT USING 1480
1500 IMAGE "OPERATING TIME",7X,D
     DDDD," HOURS"
1510 PRINT USING 1500 ; H1
1520 IMAGE "AVE POWER OUTPUT",6X
     ,DDDD.DD," KW"
1530 PRINT USING 1520 ; P6
1540 IMAGE "CAPACITY FACTOR",8X,
     D DDDDDDD
1550 PRINT USING 1540 ; F1
1560 IMAGE "ENERGY OUTPUT",4X,DD
     DDDDDDD," KW-HR"
1570 PRINT USING 1560 ; T2
1580 IMAGE "RECOVERY FACTOR",8X,
     D DDDDDDD
1590 PRINT USING 1580 ; F2
1600 IMAGE "COST OF ENERGY",6X,"
     $",D.DDD "/KW-HR"
1610 PRINT USING 1600 ; C9
1620 IMAGE "UNIT SAVINGS",9X,"$"
     ,DDD DD,"/M^2"
1630 PRINT USING 1620 ; T4
1640 END
```

## APPENDIX C

## USAFA SITING EXTREMES SUMMARY

### 1. INTRODUCTION

Many hazards exist which may have a direct impact on the siting of wind turbines. This Appendix deals with 15 potential hazards as outlined by Battelle Northwest Laboratory in their "Draft Handbook for Siting Large Wind Energy Conversion Systems" (10). Each hazard is listed individually and the local extremes for the Air Force Academy considered with respect to impacts on wind machine siting. Many of these extremes will be of more concern to the turbine designer than to the site surveyor, yet they should still be addressed. Specific references from which these extremes were summarized are contained in (3).

### 2. SOLAR RADIATION

Sunshine, in addition to being the driving force behind the wind, may cause material deterioration. Ultraviolet deterioration of polymers, for example, could have a detrimental effect on machine life and maintenance costs. The Air Force Academy receives a good deal of solar radiation due to its dry climate and high altitude. The average number of hours of sunshine per year is 3000.

TABLE C-1: USAFA SOLAR RADIATION

| Period (Representative Month) | Hours of Sunshine Month | Langleys/day |
|---|---|---|
| Winter (Jan) | 200 - 220 | 200 - 250 |
| Spring (Apr) | 240 - 260 | 500 - 550 |
| Summer (Jul) | 320 - 360 | 600 - 650 |
| Fall (Oct) | 240 - 280 | 300 - 400 |
| Annual | 250 | 400 |

3. EXTREME TEMPERATURES

Temperature extremes may affect the performance of machine parts and lubricants and also the material properties of its components. The depth of frost penetration is also a consideration for proper foundation design. The temperature extremes for USAFA are 100°F (38°C) and -32°F (-35°C). The frost line may extend to 30 inches within this area.

TABLE C-2: USAFA TEMPERATURE EXTREMES

| Period (Representaive Month) | Monthly Mean Maximum | Monthly Mean Minimum |
|---|---|---|
| Winter (Jan) | 41.0°F | 16.1°F |
| Spring (Apr) | 59.2°F | 33.1°F |
| Summer (Jul) | 84.4°F | 57.0°F |
| Fall (Oct) | 64.2°F | 36.8°F |
| Annual | 61.4°F | 35.4°F |

4. BLOWING DUST

Dust can cause damage to a wind machine if it is not sealed or maintained properly. Dust may penetrate the machine housing to cause excessive wear on moving parts. At the Academy, the frequency of dust is not large, but occasional wind storms may actually sand blast the machine. Painted surfaces should be impact resistant to minimize this damage.

TABLE C-3: USAFA DUST LEVELS

| Period (Representative Month) | % of Dusty Hours (visibility > 7 miles) |
|---|---|
| Winter (Jan) | 0.1 - 0.5 |
| Spring (Apr) | .025 - 1.0 |
| Summer (Jul) | 0.0 - 0.2 |
| Fall (Oct) | .005 - 0.4 |
| Annual | 0.2 - 1.0 |

5. SNOWFALL

Snowfall's greatest detriment is to limit the access to the more remote locations for servicing of a wind machine. Snow could also accumulate inside the machine housing and cause damage to electrical components. At the Academy the annual snowfall is 40 inches with whiteout or blizzard conditions not uncommon during periods of snowfall. There would be approximately 10 days per year when snowfall could prevent normal traffic from reaching the more remote locations.

6. ICING

The accumulation of ice on the rotor blades, tower or power lines could lead to damage and/or loss of power. Glaze ice is the most damaging type and is caused by freezing of rain on the colder surface of the machine. Rime ice is formed by the condensation of water vapor which has been super cooled and, when it collects on a structure, is much less dense and, therefore, less damaging than glaze ice. The Academy would be subject to glaze ice in excess of 1/4 inch, no more than an average of once per year.

7. TURBULENCE

Turbulence and wind gusts are rapid fluctuations in the wind direction or speed. The turbulence around a wind turbine will, in general, reduce its efficiency, complicate the control system, and may induce fatigue in the blades. At the Academy turbulence can be severe, especially during thunderstorms. The site selected must be one at which turbulence levels are low and/or the machine has been designed with these turbulence levels in mind. Turbulence levels have not been measured in the present study but must be recorded prior to machine installation at USAFA or any other location.

8. EXTREME WINDS

Knowledge of extreme winds is necessary for wind machine design. For example, most wind machines have an upper limit or cut-out speed above which the blades are feathered or the machine is braked to a stop to avoid overstressing the machine. Colorado Springs reports the fastest mile (the increase of the time required for 1 mile of wind to pass a recording station) of 60 mph. Because the Academy is located against the foothills, the local winds will certainly exceed those in Colorado Springs, especially

during the chinook winds of late winter and early spring. Peak wind speeds recorded at the Academy are 90 mph.

9. HEAVY RAINS

Excessive moisture can lead to electrical circuit damage and/or corrosion. Rainfall at the Academy averages only 15 inches per year and the relative humidity is low so problems with excessive moisture should not exist.

10. THUNDERSTORMS

Thunderstorms are local violent storms caused by the rise of warm moist air and usually occur in the summer. Thunderstorms can result in severe winds, gusts, turbulence, heavy rain, hail, lightning and/or tornadoes. Although each of these results is considered separately, the combined effects during thunderstorms may be great. Colorado foothills along the front range of the Rocky Mountains are subject to almost daily thunderstorms during the summer and the Academy could expect to experience 70 thunderstorm days per year. Most of these storms will occur around 1500-1600 hours and are usually 1/2 hour in duration.

11. LIGHTNING

Electrical storms can destroy a wind turbine if it is not properly grounded and protected. Damage can be reduced, but never eliminated, by the proper design of the control system and electrical grounding. Lightning is usually associated with thunderstorms and the Academy is in a high thunderstorm frequency area. Damage due to lightning is evident on many ridge lines where trees have been scarred or burned from strikes. Instrumentation towers associated with the present project have not suffered lightning damage but static electricity in the vicinity of thunderstorms caused occasional problems.

12. HAIL

Hail can damage the blades and structure of a wind turbine by causing dents, chips and surface abrasion. The Academy is in an area of frequent hail, 12 times per year greater than 19 mm (0.75 in), and some consideration for hail protection must be considered in wind machine design. Maximum recorded hail size for the Colorado Springs area is 75 mm (2.95 in).

13. TORNADOES

Tornadoes are local, high speed (200-300 mph) circular funnels which can destroy any wind machine in its path. It is not practical to design a machine to withstand such extreme loads, but probability of tornado occurrence must be considered. In the Academy area, funnel clouds are not uncommon during the summer months but infrequently touch ground level. The probability of occurrence is approximately two every 10 years.

14. FLOODS

Flood protection is greatest in a flood plain of a valley,but since the prime sites at the Academy are on ridge lines,there is no consideration of flood protection required.

15. EARTHQUAKES

Wind machines are highly susceptible to earthquakes and structural integrity should be assured by the manufacturer. Structural designs can be modified to reduce earthquake damage in high risk areas. Colorado is in Zone 1 earthquake risk and can expect earthquakes resulting in only minor damage.


(The reverse of this page is blank)

DTIC